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Applications of the Technology Acceptance Model to Integration of the Automatic Ground Collision Avoidance System in Fighter Aircraft Operations

Casey Richardson

APPLICATIONS OF THE TECHNOLOGY ACCEPTANCE MODEL TO INTEGRATION OF THE AUTOMATIC GROUND COLLISION AVOIDANCE SYSTEM IN FIGHTER AIRCRAFT OPERATIONS

By

Casey Richardson

A Dissertation Submitted to the College of Aviation
in Partial Fulfillment of the Requirements for the Degree of
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ABSTRACT

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Title: APPLICATIONS OF THE TECHNOLOGY ACCEPTANCE MODEL TO INTEGRATION OF THE AUTOMATIC GROUND COLLISION AVOIDANCE SYSTEM IN FIGHTER AIRCRAFT OPERATIONS

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The leading cause of F-16 fighter aircraft and fighter pilot losses is ground collisions. In an effort to curb this hazard, an automatic ground collision avoidance system (AGCAS) was formally fielded for use in routine U.S. Air Force active-duty F-16 operations in 2014. AGCAS uses a high-level automation design capable of altering the aircraft's flight control system independent of pilot action.

This study explored an application of the Technology Acceptance Model (TAM) to integration of the AGCAS in fighter aircraft operations. Using data from a survey of active-duty U.S. Air Force F-16 operational fighter pilots (n=142), collected shortly after initial AGCAS fielding, an AGCAS-specific TAM was analyzed using the structural equation modeling technique. Hypotheses describing the relationships between an AGCAS-TAM's latent variables: AGCAS perceived usefulness, AGCAS perceived ease of use, and AGCAS usage behavior. The results provided evidence of the validity and utility of an AGCAS-TAM to user acceptance of high-level automation in fighter aircraft operations.

DEDICATION

For my friend and brother-fighter-pilot Captain Mark R. McDowell, who gave his life during a controlled-flight-into-terrain mishap while defending the American ideals of life, liberty, and the pursuit of happiness.

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The members of my Embry-Riddle Aeronautical University dissertation committee, my friends and colleagues in the USAF flight test community, the Air Force Research Laboratory, at NASA, and at California State University Northridge, and my family have provided support well above what anyone should or could ever hope for in life. Whatever good may come of this work, it belongs as to us all. Thank you for being great mentors, teammates, and companions. You have helped me grow into a better professional and person.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

In 2014, the United States Air Force (USAF) released the Automatic Ground Collision Avoidance System (AGCAS) as part of the operational F-16 fighter fleet's operational flight program (OFP) for variants of the aircraft utilizing digital flight control computers. This release encompassed the vast majority of active duty U.S. F-16 squadrons worldwide. AGCAS represents a significant leap in the automation level of collision avoidance protection for pilots and for aircraft systems in general, because unlike previous collision avoidance systems, AGCAS is capable of automatically maneuvering the aircraft away from the ground, independent of pilot action. In the event of an imminent collision with the ground, AGCAS overrides pilot flight control inputs, rolls the aircraft to approximately wings level, and begins a pull upward to avoid impact with a ground terrain database. This study did not delve deeply into the hardware or software technical details except to emphasize the significance of what makes AGCAS unique among collision avoidance technology.

Heretofore, collision avoidance systems onboard fighter aircraft have exclusively relied on human action to effect a change in an aircraft's flight path to avoid ground collision. Past systems aimed at reducing or eliminating flight into terrain hazards by providing pilots guidance and / or warning information of various forms and degrees, but all past systems have required pilot intervention to affect a change in aircraft flight path. AGCAS does not require pilot intervention and can take action if the pilot is directing a flight path into terrain, is spatially-disoriented, or if the pilot is completely incapacitated. With AGCAS active, the entire cycle of information gathering, decision-making, and action-taking normally relegated to pilots operating fighter aircraft while avoiding ground collision hazards is complete. AGCAS does provide an optional limited visual representation to the pilot of its information gathering and decision making processes in the form of a Heads-Up-Display (HUD) indication, but only after an AGCAS collision avoidance activation has begun (whereby the flight control system commands inputs independent of the pilot) is the pilot alerted to the system's decision to begin an avoidance maneuver. Activations can and do also occur absent the HUD displayed indication, known as chevrons due to their display shape. Therefore, AGCAS represents a jump in automation level that is unprecedented in fighter aircraft operations which inherently involve pilots performing high risk tasks with small time margins to avoid ground collision.

A business case evaluation for automatic collision avoidance technology (ACAT) that included AGCAS and an air-to-air collision avoidance system (Auto ACAS), performed in 2006, projects that ACAT will prevent the loss of $843.3 million in materiel assets for the F-16 fleet alone over a period of 24 years. Should ACAT be implemented in other fly-by-wire aircraft across the USAF and U.S. Navy fleets, the systems are projected to prevent the loss of 136 aircraft, 78 pilots, and $6.7 billion in materiel assets for the DoD. This represents a return on investment of $6.2 to $1 over the same time period (Defense Safety Oversight Council, 2006).

In December 2014, Lockheed Martin company presented data at the annual F-16 System Safety Group that showed relative percentages for F-16 total operational losses, whereby the aircraft was damaged beyond repair, for all F-16 airframes worldwide prior to December 2014. These relative percentages and the associated cause of the loss is shown in Figure 1.

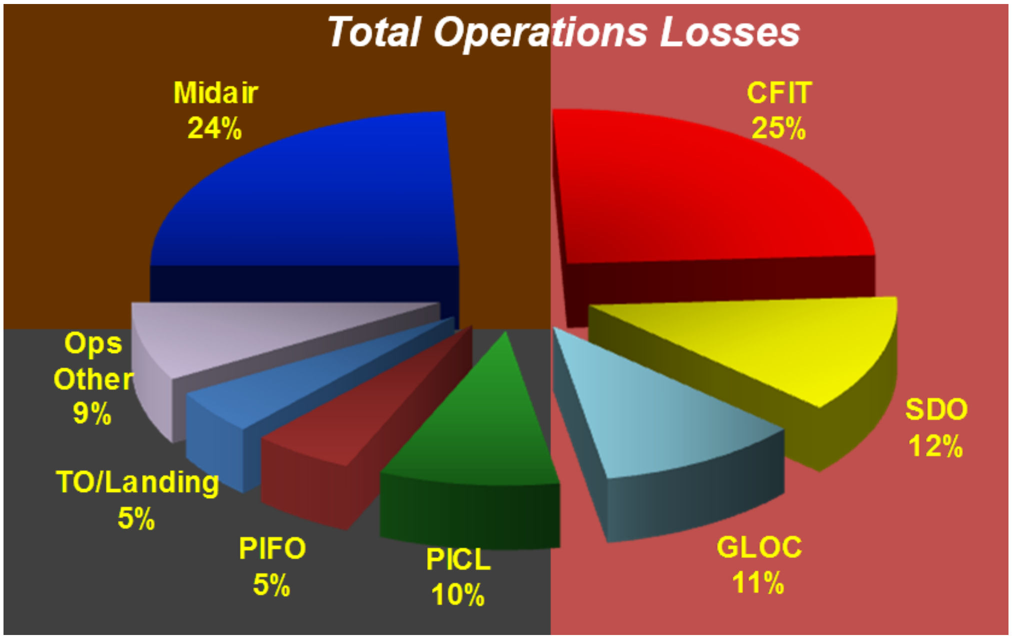

Figure 1. Total F-16 aircraft losses worldwide prior to Dec 2014. Adapted from "F-16 Total Operational Losses", by Lockheed Martin, 2014.

The entire right side of the graphic in Figure 1, 48% of total losses, represents all F-16 aircraft losses associated with ground collision. The acronyms associated with the relevant losses include controlled flight into terrain (CFIT), spatial disorientation (SDO), and g-induced loss of consciousness (GLOC). There are subtleties with the assignment of these labels to the individual causes of aircraft losses and not all F-16 organizations agree among the definitions. However, what is important to note is the majority of aircraft losses are the result of impact with the ground for F-16 operations, in general. AGCAS flight test data has shown that 98% of the historical incidents involving ground collision in the F-16 would have been prevented by AGCAS (Swihart et al., 2011).

AGCAS, therefore has potential to prevent up to 47% of total aircraft losses based on historical aircraft mishap data.

Because the added benefits of a system like AGCAS are so compelling, it may seem obvious that AGCAS was a safety system worth implementing as quickly as possible. However, the system's research history paints a clear picture of a system developed mostly in significant fits and starts (Niedober et al., 2014). Development and research to make this technology possible began thirty years ago, and many stakeholders have been involved along the way (Moore, 2013). Unfortunately, during AGCAS's developmental history there have been many stakeholders and budgetary decision-makers who were convinced that this type of technology would either not be technically viable in the field and / or would ultimately cause more harm than good. Stated another way, AGCAS was significantly delayed, and many aircraft and pilots were lost over the last thirty years because of a lack of acceptance and trust in such a system despite overwhelming technical achievement and inflight demonstration of the system's potential capability to prevent ground collisions. Many key institutional decision-makers between 1984 and 2014 were simply unconvinced that the community of fighter pilots was capable of accepting an automated system that could override pilot flight control commands.

Despite the low support afforded AGCAS development during its long and frenzied history, a few champions of the technology kept the program alive by associating its development with other research programs (Moore, 2013). In 2003, the technology received a significant boost when the Secretary of Defense's initiative to reduce fighter aircraft mishaps, for which flight into terrain represented the most significant cause of aircraft losses, was reinvigorated. Around this time, the program was re-baselined around a guiding philosophy that recognized human limitations would require a fully automated system in order to realize actual reductions in ground collisions. This re-baselining was inspired by flight test research that clearly demonstrated why ground collision avoidance systems that were not fully automated had all failed to significantly reduce aircraft losses due to ground collisions (Swihart et al., 2011).

The renewed effort was supported by the Defense Safety Oversight Council in 2007 when it invested $2.5 million to start a program collectively known as the Automatic Collision Avoidance Technology (ACAT) / Fighter Risk Reduction Program (FRRP) (Niedober et al., 2014). The ACAT/FRRP initiative provided funding and other resource support that revitalized AGACS. Additionally, ACAT was re-organized around a simple over-arching strategy with three design principles: 1) Do no harm, 2) Do not impede, and 3) Avoid collisions (Niedober et al., 2014). These three goals were rigorously and methodically pursued in priority order during system development and flight testing until the system was proven to be extremely mature. After hundreds of test flights, excruciating analyses and improvements to the system over another decade of developmental work, the decision was finally made to release AGCAS to the field. In 2014, operational F-16 pilots began flying with AGCAS in training and in combat. As of the spring of 2017, AGCAS has already prevented the loss of at least four F-16 aircraft and saved four pilot’s lives.

The system’s final stage of research was principally spearheaded by the U.S. Air Force Research Laboratory (AFRL) because it recognized the significance of this milestone and its uniqueness for study of the human element as well as the technical parts. As such, the AFRL's Office of Scientific Research initiated case studies of AGCAS during its early research and development phases as well as during its operational release. Prior to release, AFRL researchers studied AGCAS stakeholders to include experimental test pilots, managers, and engineers. Studies, such as those done by Koltai et al. (2014a) and Koltai et al. (2014b) provided a window into the expected perceptions of the operational users and offered predictions of the end users likelihood of successful incorporation of AGCAS. Test pilots, managers, and engineers thus served as the only available population at the time to act as AGCAS users for study. Since the release of AGCAS, the AFRL has extended this research into a longitudinal study with the intent to directly observe and measure the actual end users, the operational pilots, during their integration and use of AGCAS in the field. This ongoing study is organized under the name Enhancing and Supporting Auto-GCAS Acceptance and Trust Calibration: A Longitudinal Field Study of Auto-GCAS Implementation (Fergueson et al., 2016; Lyons et al., 2016; Lyons et al., in press).

In the fall of 2015, the first round of data collection for the Lyons study, which included surveys and in-person interviews of operational pilots, was conducted. This dataset represents the only available data to describe integration of a high-level automated system capable of overriding pilot commands during high-risk, low-time-available flight tasks. The Lyons study is organized to focus on the concept of trust and trust antecedents as they develop in a community of pilots over a long period of several years (Lyons et al., 2015). The independent analysis of an AGCAS based TAM described herein was symbiotic to Lyons et al. (2015) but focused instead on the concept of acceptance behavior rather than the concept of trust. The Lyons et al. (2015) study centers on a dynamic trust model described by Lee and See (2004). The goal of this study was to determine the influence of factors in the core technology acceptance model (TAM), first suggested by Davis (1986), that affected the positive acceptance behavior of pilots with respect to their use of AGCAS. This study may also provide useful suggestions for effectively integrating high-level automated systems into flight operations on a shorter timeline than was required during AGCAS's developmental history. In the future, technology developers may want to focus on those factors that are important for increasing positive initial pilot acceptance behavior.

To date, much effort has been expended researching and solving the technical and programmatic challenges involved with designing, testing, and fielding ACAT. However, there is a dearth of understanding of the acceptance and trust of the technology's end users. The principal reason for this lack of understanding surrounding integration of ACAT systems is that it is a fundamentally new type of safety system in fighter aircraft operations. At first glance, it is easy to assume that ACAT systems are much like other types of automation already commonplace in aircraft operations. However, ACAT is significantly different than any previously integrated automated system. Another contributing factor for the lack of research into pilots' trust and acceptance of ACAT systems was the resource constrained environment in which the technology was created.

For decades, research into ACAT type technologies have enjoyed support of aviation safety stakeholders but struggled with gaining budget stakeholders buy-in. The lack of budgetary buy-in for ACAT systems have historically been driven by doubts about technical feasibility, return on investment potential, and organizational and cultural factors. As a result, ACAT was developed by a few persistent research "champions," and now that the technology has been demonstrated as both technically achievable and financially viable, end users have been extremely supportive of integration of ACAT into their operational aircraft fleets.

Ideally, end user considerations are normally considered early in aircraft system development. However, because of the reasons already mentioned, ACAT was developed and fielded without a deep understanding of end user considerations that would garner rapid user acceptance. Specifically, there exists significant potential for the pilots who will use these systems to have adverse reactions to ACAT system integration. Research findings from the experimental test pilots involved with the development of ACAT's first useable system, AGCAS, indicated that there was a significant possibility of pilots becoming mis-calibrated to the technology's capability (Niedober et al., 2014). The threat of this mis-calibration is that the pilots may either underuse or overuse ACAT in ways that were not intended by the developers. Analogous examples of this type of mis-calibration of trust or lack of acceptance by an automated system's end user from other non-aviation industries have revealed that potential safety benefits may be significantly reduced or lost entirely. If the user of a safety system does not develop a calibrated trust or if the user fails to accept the system, the entire system is not optimized regardless of the capability of the specific physical hardware or software. The Lyons et al. (2015) study is focused on understanding calibrated trust, and this study focused on understanding the user's acceptance of AGCAS.

Significance of the Study

High-level automation systems capable of overriding pilot flight control commands have heretofore been excluded from fighter aircraft operations which require high risk activities with short reaction times in order to avoid catastrophic hazards. AGCAS represents a significant opportunity to study an early adoption of such a high-level automation system by end users in a field setting. To date, no other research study has analyzed AGCAS, or any other ACAT-like system, with respect to the users' acceptance behavior. A few studies were conducted before AGCAS release to make predictions about potential threats to users' acceptance and trust of AGCAS, but these studies used developmental test pilots, engineers, and program managers as respondents. The dataset from the Lyons et al. (2015) study represents the first and only response data from the actual users, operational F-16 fighter pilots, ever collected or analyzed.

The USAF and other Department of Defense (DoD) agencies are already researching other similar ACAT systems for integration into its operational aircraft fleets. Lessons learned from AGCAS development and operational integration may provide a vital first look into what future stakeholders of these systems may want to consider during research, development, and effective fielding to their end users in order to promote pilots' positive acceptance behavior.

Statement of the Problem

Integration of highly automated aircraft systems holds the potential to overcome some human limitations. Within the DoD, many new systems are being considered for integration into aircraft operations to improve safety and mission effectiveness. The benefits of automated systems cannot be realized if pilots reject them. Knowledge gained from studying pilots' acceptance behavior with respect to AGCAS may allow future stakeholders to make reasonable inferences about some factors that are important to achieving positive pilot acceptance of highly automated aircraft systems. This study presents an AGCAS-specific version of the technology acceptance model (AGCAS-TAM) for analysis with respect to F-16 pilots' acceptance of AGCAS. The AGCAS-TAM describes the interaction among users' perceived utility, perceived ease of use, and usage behavior.

Purpose Statement

This study capitalized on the release of AGCAS as the first ACAT system to operational fighter pilots in order: 1) to gain a better understanding of the pilots' acceptance behavior with respect to a high-level automated system capable of overriding pilot commands during high-risk, low-time-available flight tasks. This study: 2) demonstrated the validity and utility of the AGCAS-TAM as a model for future research efforts that involve ACAT-like systems. The core TAM, upon which the AGCAS-TAM was built, provided a starting framework with a robust model (King & He, 2006) that was developed with the goal of evaluating a proposed system's likelihood of success in its development (Davis, 1986). This study: 3) provided useful suggestions for future ACAT or ACAT-like programs to promote effective user acceptance of high-level automated systems.

Research Question and Hypotheses

With respect to F-16 pilots' acceptance of AGCAS, what are the relationships among the factors: AGCAS perceived usefulness, AGCAS perceived ease of use, AGCAS behavioral intent, and AGCAS usage behavior?

The hypotheses to be tested with respect to the application of an AGCAS-TAM are:

- H1: Pilots' perceived usefulness of AGCAS (APU) has an influence on pilots' AGCAS behavior intention (ABI).
- H2: Pilots' perceived ease of use of AGCAS (APEU) has an influence on pilots' perceived usefulness of AGCAS (APU).
- H3: Pilots' perceived ease of use of AGCAS (APEU) has an influence on pilots' AGCAS behavioral intention (ABI).
- H4: Pilots' AGCAS behavioral intention (ABI) is related to pilots' AGCAS usage behavior (AUB).

Delimitations

This study leveraged quantitative data from the closed-ended survey questions from the Lyons et al. (2015) study to explore the applicability of an AGCAS-TAM built on the core TAM first suggested by Davis (1986) to initial user acceptance of AGCAS. The quantitative variable data supported quantitative data analysis techniques.

The archival Lyons et al. (2015) data represented the best and only available data for this study. There are significant bureaucratic barriers to entry for performing research on a group of government employees which would prevent direct measurement of F-16 operational pilots specifically for the purpose of exploring the construct of acceptance. The Lyons et al. (2015) AGCAS study was built first around the construct of trust with acceptance only as a secondary construct of interest. In some instances where these two constructs differed, individual survey questions were prioritized to capture trust concepts in order to meet AFRL's organizational and funding needs. However, the author was an active participant in the development of the Lyons et al. (2015) survey instrument and data collection. Therefore, the closed-ended survey questions intended for SEM analysis were planned to correspond with TAM constructs of acceptance behavior as well.

Focusing on the closed-ended survey questions will permit structural equation model (SEM) analysis techniques that measure the relationships of the TAM as it relates to AGCAS acceptance behavior. The open-ended survey question responses and the in-person interview responses in the Lyons et al. (2015) study were not quantifiable in a manner conducive to SEM analysis methods, and were not used in this study.

Finally, the original TAM first suggested by Davis (1986) was chosen for this study because it represents a core foundation of a model that has been widely cited and modified across a wide spectrum of disciplines with consistent validity (King & He, 2006). The initially proposed AGCAS-TAM was built using the core TAM. The final modified AGCAS-TAM described in Chapters IV and V was the result of model fit analysis using the survey data. During analysis, it was discovered that the survey data was collected too late to describe behavioral intent in a meaningful way. This modification and it's ramifications on the research question and hypotheses is discussed further in Chapter V.

Limitations and Assumptions

As of the writing of this study, AGCAS has been successfully and effectively integrated in to the operational F-16 fleet. There have been a few minor localized setbacks and several individual flying units have imposed short-term, temporary internal restrictions on AGCAS use at various times. However, these restrictions have, to this point, been isolated events related to hardware issues identified shortly after release. These hardware issues are not inherently part of AGCAS itself and, as hardware problems have been resolved, system use has predominantly followed a common policy across the community of F-16 pilots in general. The common use policy in the F-16 operational pilot community mirrors closely with policies in place among the test pilots who have been flying with AGCAS for several years. As a whole, this study assumed that the community of F-16 pilots flying with AGCAS have accepted it for use in daily operations, and short-term hardware issues in individual flying units did not appreciably affect the survey question values.

A limitation of this study was that the sample size is fixed because the data used is archival. As described in the methodology section of this study, the sample size was sufficient for SEM analysis methods only for a limited number of latent variables. The nature of SEM is that the inclusion of more latent variables typically requires a larger sample size in order to achieve meaningful results. The sample size available for analysis supported up to four latent variables. The inclusion of more latent variables would have required methodology considered outside the scope of this study.

Definitions of Terms

Acceptance	means to voluntarily choose to use. In addition to key decision-makers in the DoD who choose to release a system to the users, it is possible for individual pilots to choose not to use AGCAS. The system can be disabled by each pilot via an in-cockpit interface.
Automatic	implies a transfer of control from human to a machine system.
Behavioral Intention	describes an individual's stated evaluation of his or her intent to perform certain actions.
Usage Behavior	describes the actual actions taken by a person or groups of persons.
F-16	is an aircraft, but it is also a system of systems. It is a multi-role fighter aircraft capable of a wide variety of training and combat operations.
Operational Pilot	refers to the typical training or combat oriented pilot who is focused on operating the F-16 for a purpose beyond evaluation of the aircraft or aircraft subsystems themselves. Operational pilots are the end-users of the F-16.
Perceived Usefulness	describes the operational pilot's perception of the utility of AGCAS as a system which promotes safe flight operations.
Perceived Ease of Use	describes the operational pilot's perception of workload to use AGCAS.

Test Pilot	refers to developmental and experimental test pilots who are the first to fly and evaluate any new aircraft systems or subsystem with the goal of maximizing system utility for the operational pilot.

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List of Acronyms

AAM	Automation Acceptance Model
ABI	AGCAS Behavior Intention
ACAT	Automatic Collision Avoidance Technology
AFRL	Air Force Research Laboratory
AGCAS/Auto GCAS	Automatic Ground Collision Avoidance System
AGFI	Adjusted Goodness-of-Fit Index
AMOS	Analysis of Moment Structures
APEU	Perceived Ease of Use of AGCAS
APU	Perceived Usefulness of AGCAS
AUB	AGCAS Usage Behavior
AVE	Average Variance Extracted
CFA	Confirmatory Factor Analysis
CFI	Comparative Fit Index
CFIT	Controlled Flight into Terrain
CR	Construct Reliability
DBTC	Database Terrain Cueing
DoD	Department of Defense
DTED	Digital Terrain Elevation Data
df	Degrees of Freedom

FRRP	Fighter Risk Reduction Program
GFI	Goodness-of-Fit Index
HUD	Heads Up Display
ICAS	Integrated Collision Avoidance System
INS	Internal Navigation System
IRB	Institutional Review Board
MCAR	Missing Completely at Random
MI	Modification Indicators
NFI	Normed Fit Index
OFP	Operational Flight Program
PGCAS	Predictive Ground Collision Avoidance System
RMSEA	Root Mean Square Error of Approximation
SEM	Structural Equation Model
SPSS	Statistical Package for the Social Sciences (SPSS) software
TAM	Technology Acceptance Model
TPB	Theory of Planned Behavior
TRA	Theory of Reasoned Action
TSPI	Time, Space, and Position Information
USAF	United States Air Force

CHAPTER II

REVIEW OF THE RELEVANT LITERATURE

This chapter includes three sections. The first section discusses the uniqueness of AGCAS over previous collision avoidance systems. AGCAS will be compared to two legacy F-16 collision avoidance systems already fielded but which have had little impact on reducing ground collision incidents. The second section will discuss the state of the theory in the literature regarding technology integration concepts as they relate to higher level automation schema acceptance. Particular emphasis will be made on technology acceptance in this study in order to complement ongoing AGCAS trust behavior research efforts and establish a baseline for understanding AGCAS acceptance behavior. Finally, this chapter concludes with a discussion of the research framework and hypotheses, to include the original proposed theoretical model's pre-analysis pairing of observed variables with latent variables based on subject matter opinion.

Uniqueness of AGCAS

To automate means to transfer control of a task from human to a machine system. Parasuraman, Sheridan, and Wickens (2000) describe automations as having:

> … a computer carry out certain functions that the human operator would normally perform. The automation can differ in type and complexity, from simply organizing the information sources, to integrating them in some summary fashion, to suggesting decision options that best match the incoming information or event to carry out the necessary action. (p. 287)

Parasuraman, Sheridan, and Wickens (2000) describe the type and complexity of automation as applying to four broad classes of functions that are notionally accomplished serially for any given task to be accomplished. These four functions are information acquisition, information analysis, decision and action selection, and action implementation. While these four serial functions are simple and not all inclusive of all the facets of any given task in general, they are useful for making comparisons between various types of automated systems. A comparison of the various systems applicable to ground collision avoidance in the F-16 can be made using this simple model.

The F-16 includes several systems that provide guidance or warning to the pilot in order to prevent undesirable ground impact. For example, two such systems include database terrain cueing (DBTC) and predictive ground collision avoidance system (PGCAS). DBTC is a guidance system that provides a visual indication to the pilot via the heads-up display (HUD) about where to maneuver the aircraft's flight path in order to avoid the ground by a pilot-selectable terrain clearance altitude. Using DBTC requires the pilot to turn on DBTC guidance, select a desired above ground level (AGL) altitude, and to make flight control commands which position the aircraft's displayed flight path in sync with a DBTC cue in the HUD. DBTC provides flight path guidance based on time, space, and position information (TSPI) provided by the aircraft's internal navigation system (INS) solution and pre-loaded digital terrain elevation data (DTED). DBTC is a passive guidance system that does not actively look for obstacles or confirm the accuracy of the INS or DTED information provided. Additionally, if the pilot chooses not to follow DBTC indications, the system provides no additional feedback to the pilot of impending ground collision hazards. Using an automation level analysis similar to

Parasuraman, Sheridan, and Wickens (2000), it is possible to evaluate DBTC's automation level at each functional class. This analysis is shown in Figure 1.

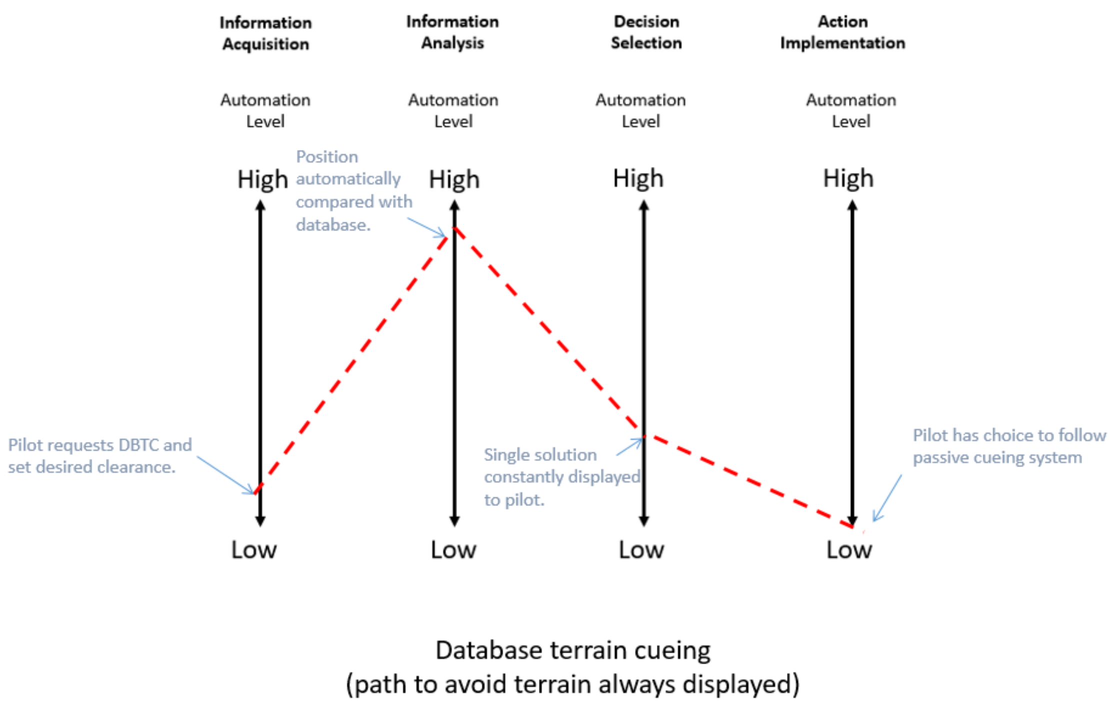

Figure 2. DBTC automation level analysis.

Compared with DBTC, PGCAS operates at a higher level of automation, as shown in Figure 2. Unlike DBTC, PGCAS does not require pilot action to activate the system. PGCAS is on at aircraft startup. Like DBTC, PGCAS automatically compares the aircraft's INS solution TSPI to DTED information in order to predict ground collision hazards. PGCAS also automatically decides when to display warning information to the pilot based on the remaining time available before ground collision is unavoidable. Only the last functional class, action implementation, requires pilot intervention.

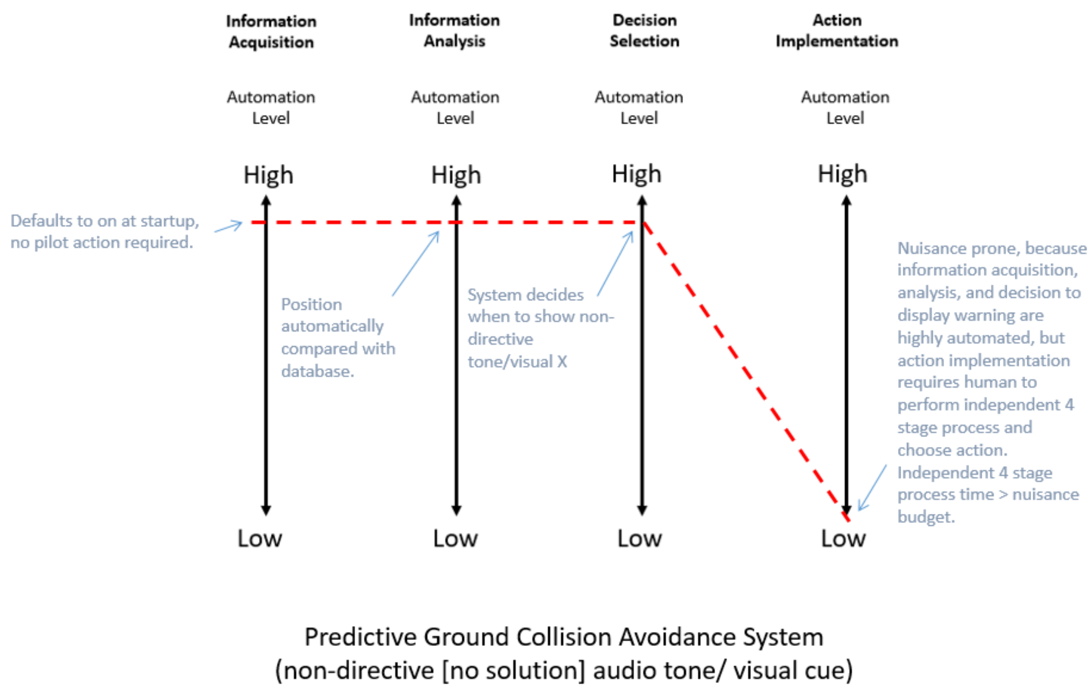

Figure 3. PGCAS automation level analysis.

Comparing these guidance and warning systems with the Parasuraman, Sheridan, and Wickens (2000) scales makes it relatively easy to visualize the differences between types of collision avoidance systems. This same analysis can be applied to AGCAS and illustrate why it is fundamentally different and worthy of study.

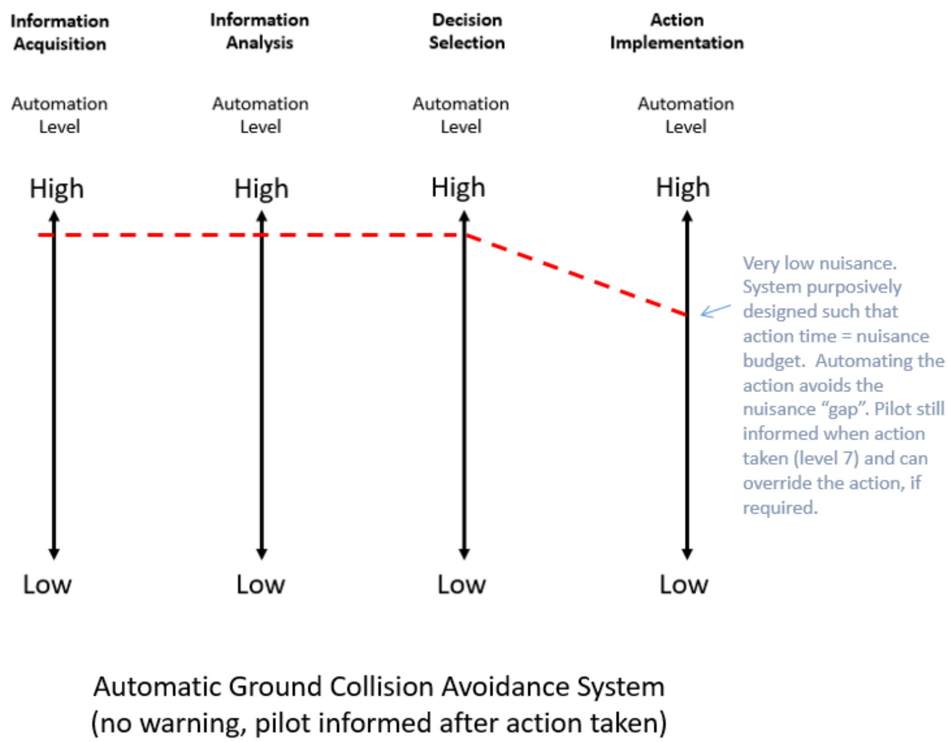

Figure 4. AGCAS automation level analysis.

Figure 4 shows an analysis of the four functional classes for AGCAS. Of particular note is the final step in the process, action implementation. This step is accomplished by AGCAS automatically, and the system only necessarily informs the human after taking action, which is consistent with a level 7 automated system on Parasuraman, Sheridan, and Wickens' (2000) ten-level scale of automation of decision and action selection shown in Figure 5.

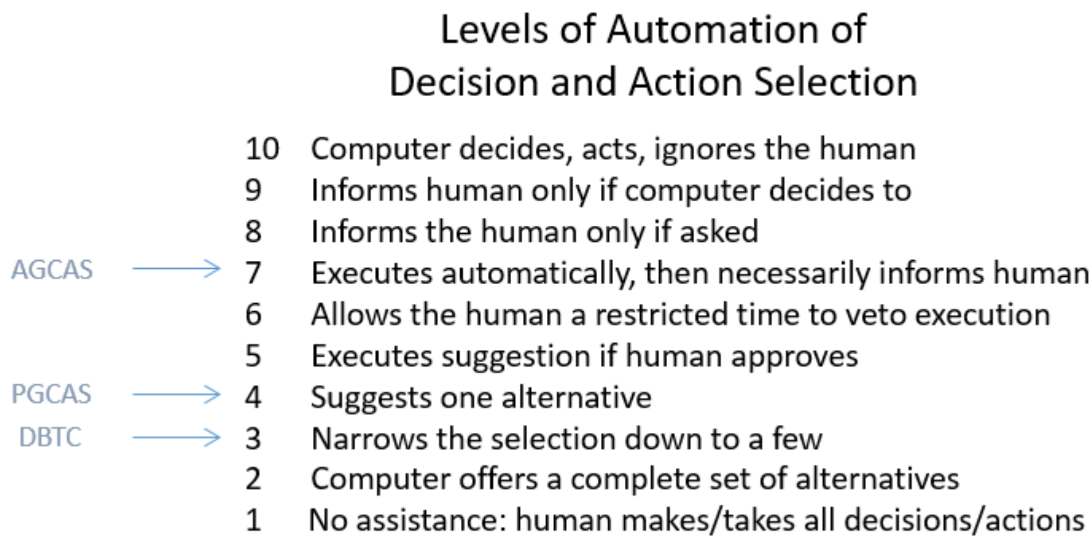

Figure 5. Comparison of F-16 ground collision avoidance systems to the levels of automation of decision and action . Adapted from "A model for types and levels of human interaction," by Parasuraman, Sheridan, and Wickens, 2000, IEEE Transactions on Systems, Man and Cybernetics, Part A: Systems and Humans, 30*(3), 286-297*.

Compared with past systems, such as DBTC and PGCAS, AGCAS is a significant jump from a level 3 or 4 system to a level 7 automated collision avoidance system. It is this leap that makes AGCAS fundamentally so different than any past collision avoidance system and thus makes it worthy of focused research. In particular, significant time and effort has already been spent researching the technical aspects of AGCAS, but there is a dearth of understanding of how to integrate a high-level automated system capable of manipulating an aircraft's flight path independent of pilot action into real-world fighter aircraft operations.

Past and Ongoing AGCAS Integration Research

Prior to AGCAS release for operational F-16 pilot usage, studies such as those by Koltai et al. (2014a), Koltai et al. (2014b), and Niedober et al. (2014) focused on predicting end user trust behavior from observations among stakeholders in the development and testing of the system. These studies used responses from system designers, flight test engineers, management stakeholders, and F-16 test pilots to make estimates and inferences about dynamic trust behavioral implications. Following the release of AGCAS to the F-16 operational pilot community in 2014, studies such as Lyons et al. (2016), Lyons et al. (2015), and Lyons et al. (in press) have focused on observing end user trust behavior and comparing observed F-16 pilot AGCAS trust behavior with the previously predicted behavioral implications. These studies rely on the theory by Lee and See (2004) who proposed that organization trust behavior evolves and is a dynamic behavior that eventually settles on a long-term equilibrium, whereby user trust behavior becomes calibrated with an automated systems' capabilities.

This study was complementary to the ongoing trust development studies but does not duplicate effort. Rather than exploring longitudinal trust behavior, this study leverages existing data from the trust studies to explore initial pilot acceptance behavior. There are no existing studies to document pilot acceptance of a high-level automated system, such as AGCAS, that is capable of arresting control from the pilot during intentional high risk, low-time-available flight conditions. Understanding pilot acceptance behavior with respect to AGCAS will fill a gap in understanding pilot acceptance behavior for these type of systems. This study helped realize Davis' (1986) practical goal to "provide valuable information for systems designers and implementers.

Designers would be better equipped to evaluate design ideas early in the system development process and make informed choices among alternative approaches” (p. 12).

There are several high-level automation technologies in various stages of development currently being considered by the DoD that would likely benefit from a deeper understanding of pilot acceptance behavior. For example, the F-16 development community has already begun flight testing of an automatic air collision avoidance system (Auto ACAS) targeting the next leading cause of aircraft losses, mid-air collisions, as shown in Figure 1 (Richardson, Eger, & Hamilton, 2015). The current plan for Auto ACAS is to integrate it with Auto GCAS into a combined system under the umbrella name of integrated collision avoidance system (ICAS) (Norris, 2016). The release of ICAS to the operational pilot community will likely affect similar behavioral responses as Auto GCAS, therefore stakeholders would probably benefit from knowing how the end user’s come to accept these types of systems.

Because this study found quantitative evidence that the widely-accepted technology acceptance model (TAM) is useful in describing Auto GCAS acceptance behavior, it may be reasonable to expect that the large body of literature related to TAM may also prove useful for stakeholders of similar systems. For example, to date, ICAS system designers and implementers are developing their systems while relying only on qualitative results or informal analysis methods of inconsistent anecdotal sources of feedback from a few key points-of-contact in the F-16 pilot community. A unifying theory, supported by quantitative evidence, to describe how operational fighter pilots come to accept high-level automated systems, which can intervene during high-risk, low-time-available flight maneuvers, has not yet been documented. Therefore, designers and implementers of these types of systems lack a reliable method to predict pilots' acceptance behavior. This study provided a first quantitative look at the F-16 operational pilot community's acceptance behavior with respect to unique Auto GCAS operationalized constructs and may serve to justify future exploration of theoretical extensions of TAM to better describe pilot acceptance behavior.

Technology Acceptance Model Background

The researcher proposes to analyze the validity of the TAM (Davis, 1986) to AGCAS integration into fighter operations. The TAM was primarily chosen as a starting framework for this study for two reasons. First, the practical goals that Davis (1986) cited as reasons for developing this model are closely aligned with the goals of this research study. Principally, having a valid theoretical basis for user acceptance would provide useful information for evaluating the "relative likelihood of success of proposed systems early in their development, where such information has greatest value" (Davis, 1986, p. 7). Secondly, the TAM has been used and evaluated extensively in the literature and has proven to be a robust model for many applications well beyond its origins (King & He, 2006).

The TAM was first suggested by Davis in his 1985 dissertation (published in 1986). It has undergone many iterations and taken various forms as researchers have attempted to modify the TAM to the needs of each individual research topic. In 2006, King and He performed a meta-analysis of 88 TAM empirical studies that demonstrated the model to be valid and robust. While the core TAM constructs have been modified and added to in many ways, the core constructs have remained “highly reliable and may be used in a variety of contexts” (p. 751). The core TAM is shown in Figure 6.

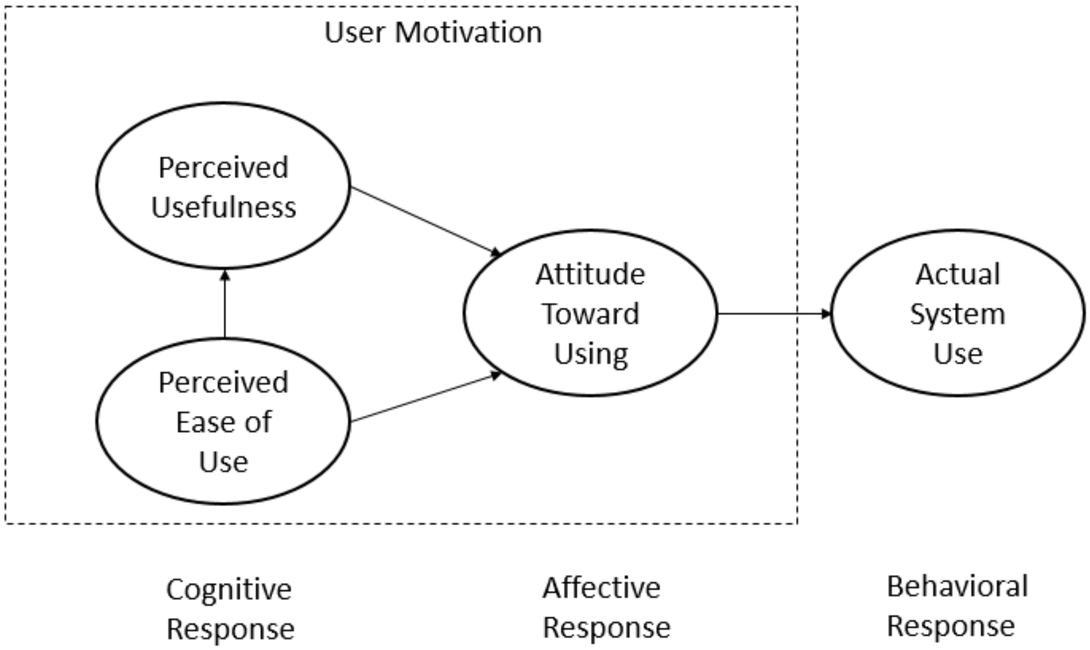

Figure 6. Core TAM describing user motivation. Adapted from “A technology acceptance model for empirically testing new end-user information systems”, by F. Davis, 1986, Massachusetts Institute of Technology.

King and He (2006) state that “TAM is based on the theory of reasoned action (TRA), a psychological theory that seeks to explain behavior” (p. 740). Also, with regards to construct reliability, these “reliabilities are consistently high with low variance, leading to the conclusion that these simple four to six measures have widespread potential utility in technological utilization situations”(King & He, 2006, p. 743).

In his meta-analysis of Fishbein and Ajzen’s theory of reasoned action (TRA), Callahan (1998) argues that “the lack of support for the bivariate assumption of the early studies, i.e., that attitude is the sole predictor of behavior, led many to suggest that attitude towards an object is only one variable that influences behavior" and that "[o]ther factors such as habits, past experience, social norms, and situational considerations needed to be addressed" (pp. 1-2). Wicker (1969) provided a comprehensive review of the early evolution of this bivariate relationship assumption, between attitude and behavior, whereby he concludes that there is "little evidence to support the postulated existence of stable, underlying attitudes within the individual which influence both his verbal expressions and his actions" (p. 75). As a result, other theories emerged that attempted to explain and predict human behavior. One of these theories was the TRA, which was suggested and developed over time in several publications, such as Fishbein (1967), Ajzen and Fishbein (1970, 1974), Fishbein and Ajzen (1975), and Fishbein and Ajzen (1980). Before 1980, TRA was known as the model of behavioral intentions (Callahan, 1998). Davis (1986) used the TRA as "a starting point, a fairly general, well-established theoretical model of human behavior in psychology" (p. 13).

Davis (1989) expanded on the TAM by developing and validating measurement scales for observed variables related to the latent variables in the model perceived usefulness and perceived ease of use. Quantitative data used for the Davis (1989) scales investigation exhibited "significant empirical relationships" and "were found to have strong psychometric properties" with "self-reported measures of usage behavior" (p. 333). Davis (1993) tested the TAM with a field study of users and two end user systems. The underlying model was supported by the data, but analysis results also prompted the author to conclude that "research should consider the role of additional variables within TAM" (p. 483). Venkatesh and Davis (2000) developed an extended version of the TAM, which they called TAM2, using longitudinal field studies to explore the influences of social influence and cognitive instrumental processes on the latent variables perceived usefulness and usage intentions. Again, the underlying model was supported by the data, and the addition of external influences showed promise in accurately explaining reported behavior with some significant differences between the acceptance of "mandatory" and "voluntary" information systems. Venkatesh and Davis (2000) also concluded that "future research should seek to further extended models of technology acceptance to other important theoretical constructs," (p. 200) suggesting that the TAM could serve as a framework for customizing models of behavior to other systems operating under a wide variety of environments or conditions.

King and He (2006) performed their meta-analysis of the TAM using 88 studies with more than 12,000 observations, found consistent reliable results, and made several conclusions, to include:

(a) TAM measures (perceived ease of use, perceived usefulness, and behavioral intention) are highly reliable and may be used in a variety of contexts.

(b) TAM correlations, while strong, have considerable variability, suggesting that moderator variables can help explain the effects. The experience level of users was shown to be a moderator in a number of studies but was not pursued here because of the difficulty in identifying the experience level in studies that did not report it. It was possible to identify two moderators given the data from the sampled studies.

(c) The influence of perceived usefulness on behavioral intention is profound, capturing much of the influence of perceived ease of use. The only context in which the direct effect of (perceived ease of use) on (behavioral intention) is very important is in internet applications.

(d) The moderator analysis of user groups suggests that students may be used as surrogates for professional users, but not for ‘‘general’’ users. This confirms the validity of a research method that is often used for convenience reasons, but which is rarely tested.

(e) Task applications and office applications are quite similar and may be considered to be a single category.

(f) This sample sizes required for significance in terms of most relationships is modest. However, the (perceived ease of use)-(behavioral intention) direct relationship is so variable that a focus on it would require a substantially larger sample.

These conclusions led King and He (2006) to the summary conclusion that their “meta-analysis rigorously substantiates the conclusion that has been widely reached through qualitative analyses: that TAM is a powerful and robust predictive model” (p. 751).

Ghazizadeh, Lee, and Boyle (2012) argued that “[o]ften joint human-automation performance depends on the factors influencing the operator’s tendency to rely on and comply with automation,” and that there are sufficient parallels between automation acceptance and information system acceptance such that TAM may serve to “complement the human-automation interaction perspective from the cognitive engineering community” (p. 39). Ghazizadeh, Lee, and Boyle (2012) suggest a form of the TAM that they call the automation acceptance model (AAM), which they proposed as a model for describing the successful formation of human-technology coagency over time. This coagency is akin to Lee and See's (2004) concept of human automation trust whereby reliance and dependence behaviors are dynamic.

Although analysis of an AGCAS-TAM built on a more complex version of the TAM may be interesting, this study only investigated the applicability of the AGCAS-TAM built on the core TAM for two reasons. The first reason was to initially limit the number of unsubstantiated variables to be explored with a limited sample size. The dataset size only supports SEM analysis for a model with four latent factors, and therefore, it is impractical to attempt SEM with a model based on more than four latent factors. Secondly, recent TAM variations, such as the AAM, tend to be inherently dynamic models with feedback mechanisms that cannot be supported with the static archival data available. The data available for this study came from the first and only data collected from operational F-16 pilots using AGCAS to date. No longitudinal data yet exists to support analysis of a dynamic model.

The core TAM does have potential weaknesses and has been critiqued in the literature. Bagozzi (2007), a Davis colleague and collaborator, criticized Davis' (1986) TAM model as being too simplistic and that most follow-on efforts to expand upon the core TAM have only "constituted a broadening of TAM in the sense of introducing additional predictors for either perceived usefulness or intentions," and "almost no research has deepened the TAM in the sense of explaining perceived usefulness and perceived ease of use, reconceptualizing existing variables in the model, or introducing new variables explaining how the existing variables produce the effects they do" Bagozzi (2007, p. 244). Bagozzi (2007) was thorough in his review and critique of several popular behavioral models including TAM, the theory of planned behavior, and the theory of reasoned action. Among other critiques, Bagozzi (2007) takes issue with the deterministic nature of these models and describes many potential pitfalls in the linkages, the assumptions underlying the variables themselves, and the lack of feedback mechanisms to describe dynamic behavior changes. He also suggests a solution for these weaknesses by providing his own model called the "technology user acceptance decision making core", which he argues is more "universal" and more capable of capturing potential gaps in past models (Bagozzi, 2007, p. 250). His new model uses as a framework latent variables such as goal desire, goal intention, action desire, action intention, and a feedback mechanism he calls self-regulation, that he presumes will better capture more of the complexities that exist in human acceptance behavior in general.

However, Bagozzi (2007) does not dismiss the TAM, or other popular theories such as TRA or theory of planned behavior (TPB), outright. Instead, he states that "by any measure, TAM qualifies as a remarkable accomplishment," that "TAM has stood the test of time by being the leading model for nearly two decades", and "TAM has consistently outperformed the TRA and TPB in terms of explained variance across many studies (Bagozzi, 2007, p. 244). For the purpose of this study, which is a first exploration into acceptance behavior for a novel technology, the consistency of TAM is precisely what is needed to start research into ACAT-like systems. Davis (1986) "identified two distinct beliefs, perceived usefulness and perceived ease of use, that were sufficient enough to predict the attitude of a user toward a system" (Marangunic & Granic, 2015, p. 85). For this study, the simplicity and deterministic nature of TAM are not expected to be weaknesses. The measure of a model's value is not necessarily its accuracy at describing a complex system of systems, but instead a model may be valued for its precision and practical utility.

The TAM is a robust model with a long history of reliability and validity (King & He, 2006). While there are many man-machine systems that rely on automation, as argued previously, AGCAS is a fundamentally new and different type of automation that does not have a direct analogous technology by which to accurately compare. By using a model with a solid foundation, this new object of study can be grounded in a model with a solid foundation in the literature. A quantitative SEM analysis of the core TAM as it pertains to AGCAS provides a solid foundation for potentially fruitful future exploration of TAM variants that will probably require qualitative or mixed methods to draw useful conclusions. Without an initial quantitative analysis of the core TAM, inferences from analysis of TAM variations that rely on qualitative methods alone will have reduced persuasive strength.

The methods chosen for this study's use of TAM were consistent with typical research involving the TAM. King and He's (2006) description and summarizations from their meta-analysis of the 88 TAM empirical studies collected from indexed sources suggest the preponderance of TAM studies that yielded useful quantitative results involved collecting response data from technology users and then performing linear regression or structural equation modeling analysis methods. The archival data from the Lyons et al. (2015) study were consistent with past methods of TAM research and, as described later in this study, was sufficient for detecting medium effect sizes for an AGCAS-TAM given the fixed sample size and number of variables.

Research Theoretical Framework and Hypotheses

The proposed theoretical framework of the AGCAS-TAM that will describe AGCAS acceptance is shown in Figure 7. This framework was developed based on the literature review and with consultation with Lyons both before and after his team's data collection effort for the Lyons et al. (2015) study. The proposed hypotheses are also shown.

Table 1 shows the operational definitions of this study's constructs as it applies to AGCAS acceptance by operational (non-test) F-16 pilots.

Table 1

Operational Definitions of the Study Constructs

Construct	Operational Definition
AGCAS Perceived Usefulness (APU)	The pilots' reported degree to which AGCAS serves its intended purpose.
AGCAS Perceived Ease of Use (APEU)	The pilots' reported effort required to use AGCAS.
AGCAS Behavioral Intention (ABI)	The pilots' reported future AGCAS usage behavior.
AGCAS Usage Behavior (AUB)	The pilots' reported AGCAS interactions.

Note. Adapted from Davis' (1986, 1989, and 1993) descriptions of TAM to describe an AGCAS-specific model, AGCAS-TAM.

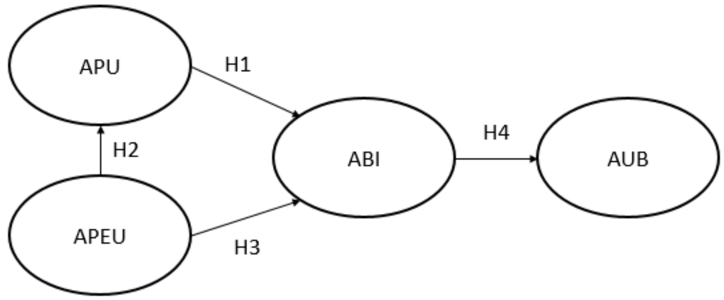

Figure 7. Graphic representation of the hypotheses between latent variables in the AGCAS-TAM.

The TAM is based on the theory of reasoned action (King & He, 2006). The theory of reasoned action (Ajzen and Fishbein 1980; Fishbein & Ajzen, 1975) is not the only popular theory for describing human behavior, but it "has been widely used as a model for the prediction of behavior intentions and/or behavior" (Madden, Ellen, & Ajzen, 1992, p. 3). In 1989, Davis expanded his 1986 introduction of TAM with descriptions of the latent variables in the model:

- "Perceived usefulness is defined here as the degree to which a person believes that using a particular system would enhance his or her job performance. This follows from the definition of the word useful: capable of being used advantageously … a system high in perceived usefulness, in turn, one for which a user believes in the existence of a positive use-performance relationship" (Davis, 1989, p. 320).
- "Perceived ease of use, in contrast, refers to the degree to which a person believes that using a particular system would be free of effort. This follows from the definition of ease: freedom from difficulty or great effort" (Davis, 1989, p. 320).

- Behavioral intention "is a measure of the strength of one's intention to perform a specified behavior" (Davis, Bagozzi, & Warshaw, 1989, p. 984).
- Usage behavior "can be predicted reasonably well from their intentions" (Davis, Bagozzi, & Warshaw, 1989, p. 997).

In his original proposal of TAM, Davis (1986) provided "empirical support" for "TAM's relationships except for the ease of use-usefulness link" (p. 67). Davis (1986) first described the relationship between perceived ease of use on perceived usefulness by stating that "since, all else being equal, a system which is easier to use will result in increased job performance for the user". The directional relationship between perceived ease of use and perceived usefulness accounts for cases where the "performance benefits of usage are outweighed by the effort of using the application" (Davis, 1989, p. 320). The TAM model's original proposed directional relationships have demonstrated consistency across the "accumulated body of knowledge regarding self-efficacy, contingent decision behavior and adoption of innovations" (Davis, 1993, p. 323). The original empirical support and the demonstrated broad utility of the model in the literature across a wide spectrum of disciplines and industries (King and He, 2006; Marangunic and Granic, 2015) suggest that the TAM model's relationships will likely hold true for AGCAS acceptance behavior as well.

A note on behavioral intention. One of the original authors of the theory of reason action, upon which the TAM was founded, Ajzen (2002) described behavioral intention as the "antecedent of behavior" and "given a sufficient degree of actual control over the behavior, people are expected to carry out their intentions when the opportunity arises" (p. 665). Behavioral intention was originally proposed by Davis (1986) as *attitude toward using* and subsequently labeled simply *attitude* for many uses (Marangunic & Granic, 2015). However, *attitude* "did not fully mediate the *perceived usefulness* and the *perceived ease of use*" variables, and so "Davis and his colleagues suggested that there would be cases when, given the system which was perceived useful, an individual might form a strong behavioral intention to use the system without forming any attitude" (Marangunic & Granic, 2015, p. 85). Marangunic and Granic (2015) refer to this early TAM modification as the parsimonious TAM. For the sake of this study, the term parsimonious will not be used in discussion, but this updated form of the TAM model, which includes this early modification by the original model's creator, was used and referenced as the *core* TAM. It represents the most consistently used basic form of the TAM.

AGCAS-TAM hypotheses. The directional relationships between the latent variables in the AGCAS-TAM are:

- H1: Pilots' perceived usefulness of AGCAS (APU) has an influence on pilots' AGCAS behavior intention (ABI).
- H2: Pilots' perceived ease of use of AGCAS (APEU) has an influence on pilots' perceived usefulness of AGCAS (APU).
- H3: Pilots' perceived ease of use of AGCAS (APEU) has an influence on pilots' AGCAS behavioral intention (ABI).
- H4: Pilots' AGCAS behavioral intention (ABI) is related to pilots' AGCAS usage behavior (AUB).

Summary of the Literature Review

By comparing three of the ground collision avoidance systems in the F-16 using automation level analysis, this literature review described the uniqueness of AGCAS as a fully automated system when compared to guidance and warning systems. Past and ongoing research of AGCAS integration centered on trust as a dynamic construct within the DoD have been described. Arguments from meta-analyses of the TAM, popular in the literature on automation, were summarized to highlight the enduring strengths of the theory. Finally, an AGCAS specific version of a core TAM has been proposed with a theoretical framework and associated hypotheses included.

CHAPTER III

METHODOLOGY

This chapter describes the methodology for assessing the AGCAS-specific TAM measurement and theoretical models' validities using quantitative variables from archival operational USAF F-16 pilots' survey response data. First, the research approach, to include a proposed initial measurement model, will be described. The dataset will also be described, to include population and sampling, source of the data, and the treatment of the data process. Finally, acceptable values for proposed indexes and estimates in the SEM model will be provided which will validate the theoretical model and test the hypotheses.

Research Approach

The research methods suggested by Hair et al. (2010) were used. For analyzing dependent relationships with multiple relationships of dependent and independent variables, Hair et al. (2010) recommends structural equation modeling (SEM). SEM is also a commonly used analysis method for research using the TAM (King & He, 2006).

Design and procedures.

The dataset already exists and was provided with permission for this study. Therefore, this study was inherently archival in nature. For a study where empirical results already exist, three steps are required: (1) assess measurement model validity, (2) specify structural model and (3) asses structural model validity (Hair et al., 2010). In general, this study used confirmatory factor analysis (CFA) tools in Analysis of Moment

Structures (AMOS) and reliability tests in Statistical Package for the Social Sciences (SPSS) to assess measurement model validity, used AGCAS-TAM as the structural model, and used SEM tools in AMOS to assess model validity. Hypotheses were tested by the estimates and their associated critical ratio significance tests that result from the SEM analysis in AMOS.

Apparatus and materials. The dataset was provided in an excel spreadsheet with interval numerical values from the survey respondents organized by questions as observed variables.

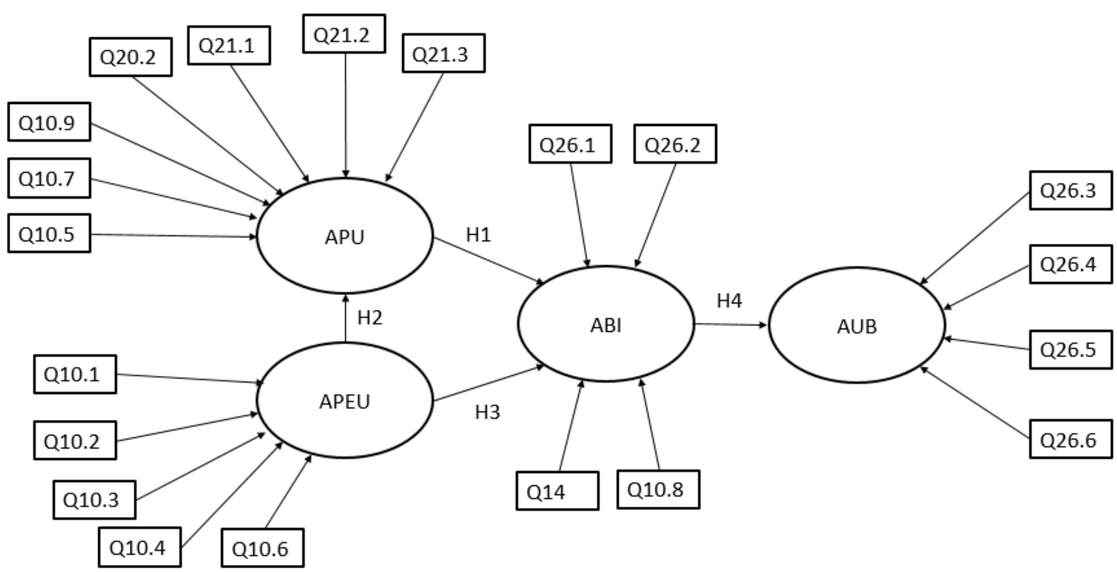

Figure 8. Proposed theoretical framework of an AGCAS acceptance technology acceptance model (AGCAS-TAM) with observed variables from Lyons et al. (2015) survey data.

In Figure 8. Proposed theoretical framework of an AGCAS acceptance technology acceptance model (AGCAS-TAM) with observed variables from Lyons et al. (2015) survey data, the question numbers (e.g. Q#) refer to the survey question numbers in the Lyons et al. (2015) study, for ease of cross referencing the original dataset.

Table 2

Question Numbers Sorted by Latent Variableshows the actual questions on the survey that correspond to each question label in Figure 8. Proposed theoretical framework of an AGCAS acceptance technology acceptance model (AGCAS-TAM) with observed variables from Lyons et al. (2015) survey data, sorted by respective latent variable.

Table 2

Question Numbers Sorted by Latent Variable

Number/name	Actual question
Perceived Usefulness	
Q10.5	I think Auto-GCAS was designed to help me
Q10.7	Auto-GCAS is reliable
Q10.9	Auto-GCAS was designed to have my best interests in mind
Q20.2	After flying in a plane equipped with Auto-GCAS, what was your perception of the overall usefulness of Auto-GCAS?
Q21.1	Auto-GCAS effectively prevents CFIT
Q21.2	I benefit from having Auto-GCAS installed on my plane
Q21.3	Other pilots benefit from having Auto-GCAS installed on their planes
Perceived Ease of Use	
Q10.1	Auto-GCAS is designed in such a way to minimize nuisance to the pilot
Q10.2	I understand the purpose of Auto-GCAS
Q10.3	I understand how Auto-GCAS senses the environment
Q10.4	I understand when Auto-GCAS will activate
Q10.6	I understand how Auto-GCAS works
Behavioral Intention	
Q26.1	I feel more confident flying with Auto-GCAS installed on my plane

Q26.2	I feel confident Auto-GCAS will protect me if I experience spatial disorientation, G-induced loss of consciousness (G-LOC), or loss of consciousness
Q14	If I experience an Auto-GCAS activation, I am comfortable reporting the activation
Q10.8	Auto-GCAS does not interfere with my ability to fly
Usage Behavior	
Q26.3	I can count on Auto-GCAS to work when needed
Q26.4	I can count on Auto-GCAS to work in emergency situations
Q26.5	I can count on Auto-GCAS to work during combat
Q26.6	I can count on Auto-GCAS to work during low-altitude flying

Note. Adapted from "Trust of an automated collision avoidance technology: A fighter pilot perspective," Lyons, J. B., Ho, N. T., Fergueson, E., Sadler, G., Cals, S., Richardson, C., & Wilkins, M, 2015, *Unpublished manuscript*.

Population and Sampling

The dataset included survey responses from 142 F-16 pilots from various U.S. Air Force bases around the world where AGCAS had been implemented into daily operations. According to the USAF F-16 system program office, the population of USAF F-16 pilots actively flying at the time of the data collection was 967, with 495 of those pilots flying an AGCAS capable version of the F-16 (S. Baker, personal communication, September 4, 2015). The sample size, n=142, therefore represents a 28.69% response rate among the population of pilots that are flying with AGCAS. However, it should also be noted that not all respondents answered all survey questions, and for at least one question, Q14, the actual sample size was as low as n=109, which is a response rate of 22.02% among pilots actively flying with AGCAS.

The dataset was archival and the sample size was therefore fixed. No more data was available for analysis besides that provided from the Lyons et al. (2015) study. Hair et al. (2010) recommend a minimum sample size of 100 for SEM analysis for models with five or fewer constructs and 150 for models with up to seven constructs. For quantitative analysis of the AGCAS-TAM with respect to AGCAS applicability, the sample size available from the Lyons et al. (2015) study should be sufficient to support the four constructs listed in Table 1 and shown in Figure 8.

Source of the Data

The data provided for this study was archival and was provided, with permission to be used for this study, by the authors of Lyons et al. (2015). Permission to use the data is attached as Appendix A. The Lyons et al. (2015) survey was administered via email, through official U.S. government email servers, to provide every pilot flying with AGCAS at 10 different U.S. Air Force installations around the world the opportunity to complete the survey. The 10 installations included in the survey distribution were chosen after consultation with several relevant government agencies such that the sample would be representative of the entire population of F-16 pilots using AGCAS.

Additionally, the Lyons et al. (2015) data were collected after formal review by a USAF institutional review board (IRB) process, and the IRB's instructions for protecting survey respondents were strictly followed. The archival data provided from the Lyons et al. (2015) study for this study were made anonymous before transmittal, and none of the information is individually identifiable. No response data can be traced back to any specific person, location, or military unit. Therefore, Protection of Human Subjects 45 C.F.R. § 46 does not apply, and this study did not involve human subjects (U.S. Department of Health & Human Services, 2014). Additionally, exempt status was confirmed by the Embry Riddle IRB. This exemption is attached as Appendix B.

The Lyons et al. (2015) study included closed-ended and open-ended questions. For this study, only responses from the closed-ended questions were used. These closed-ended questions used Likert-scale style response choices to the questions statements shown in Table 2. The Lyons et al. (2015) study used the response data from these questions under the determination that the data were continuous during analysis. However, Likert-scale style response choices have been argued by some in the literature to primarily consist of ordinal data. Fortunately, SEM has been demonstrated to be a robust analysis method for Likert scale style data whether it is considered continuous or nonmetric (Awang, Afthanorhan, and Mamat, 2006; Byrne, 2010; Hair, Black, Babin, and Anderson, 2010). Byrne (2010) summarized reviews of the issue of SEM categorical versus continuous data by establishing conditions whereupon continuous methods may be used with categorical variables: (a) where the number of category response choices is at least five; (b) the variables do not exhibit opposite skew; and (c) the data approximates a normal distribution. The archival data from Lyons et al. (2015) used in this study met these requirements, and, therefore, the data was considered continuous.

Instrument reliability. Reliability of the instrument was tested using Cronbach's alpha (α) on a random sample of the survey responses to determine internal consistency of the scales. This test was performed on the data using SPSS software. Values for α of 0.7 or greater achieve the standards for general acceptability (Hair et al., 2010). In the event low α values were found, recommendations from Field (2009) were planned for use, which include consideration of inter-item correlations of observed variables. However, this contingency did not need to be exercised in this study.

Instrument validity. Construct validity was tested using CFA in SPSS and with AMOS software. CFA helped determine correlation between variables (Brown, 2015). Construct validity testing included convergent and discriminant validity tests. Average variance extracted (AVE) and construct reliability (CR) techniques were both used as indicators of convergent validity. Discriminant validity was suggested by comparing AVE to the square of the correlation estimate (Hair et al., 2010). Acceptable values for construct validity followed the suggested values from Hair et al. (2010), to include loading estimates above 0.5, AVE of 0.5 or greater, AVE estimates for any two factors greater than the square of the correlation between the two factors, and CR of 0.7 or greater.

Treatment of the Data Process

The dataset was sanitized with respondent identification information removed before transferal from the Lyons et al. (2015) authors to the author of this study. Each respondent's response data was given a unique coded label that does not link to the respondent's identity. Therefore, all the respondents' data were anonymous. As a further precaution, however, this unique coded label for each respondent was only used to organize data during analysis and not presented anywhere in this work.

Respondents who only answered demographic information were excluded from the sample to be used in this study. This exclusion resulted in only four respondent's surveys being removed. There was no recognizable pattern or observable reason that this small number of respondents only provided demographic information and failed to answer the quantitative scale survey questions. No technical glitch was found in the administration of any survey. It was suspected that respondents who provided demographic style information only may have been limited by time constraints beyond the control of the researchers in the Lyons et al. (2015) study. This exclusion rate, 4 out of 146 respondents, did not have any significant effect on results.

For the remaining 142 responses, listwise deletion was the preferred method for handling missing values. There were 109 listwise responses, meaning there are n=109 responses after the surveys with incomplete responses for the relevant observed variables were removed. The minimum sample size, discussed previously in this chapter, was 100 for SEM analysis, given the number of latent and observed variables in the AGCAS-TAM. Therefore, while listwise deletion reduces the sample size, a large enough sample remains for SEM analysis. If the missing data are missing completely at random, then listwise deletion does not introduce bias into the SEM estimates (Allison, 2003). A comparison of the surveys with missing responses with demographic information for each respondent revealed no reason to suggest that the missing data was anything other than missing completely at random. Therefore, the sample remaining after listwise deletion is “effectively a random sample from the original sample” and “any statistical method may then be applied” (Allison, 2003, p. 547). Results of statistical tests supporting the random nature of the missing data were also calculated and are included in Chapter IV.

SEM analyzes covariance structures and therefore kurtosis may negatively impact results (Byrne, 2010). This negative impact of kurtosis may be minimized by obtaining a large enough sample size. Byrne (2010) recommends a ratio of 10, and Hair et al. (2010)

recommends a ratio of 15 respondents for each parameter to be estimated. However, the proposed measurement model in Figure 8 includes too many parameters when compared to the number of respondents in the dataset to meet either recommended ratio threshold. Therefore, if analysis had shown no acceptable adjustments to achieve acceptable model fit, tests for normality conducted in AMOS may have revealed variables with univariate kurtosis that contribute most to multivariate kurtosis. However, for the AGCAS-TAM analysis, good model fit was achieved with the measurement model using the most common estimation technique, the maximum likelihood method, as recommended by Byrne (2010) without the requirement to transform any variable to correct for kurtosis.

Finally, outlier detection was conducted with the dataset using the technique recommended by Byrne (2010) in order to detect multivariate outliers. AMOS output for Mahalanobis distance was evaluated for each case in order to compare the standard deviation units for each case, and the sample means for all variables and outliers would have been those variables which stand “distinctively apart from all the other” distance values (Byrne, 2010, p. 106). Analysis revealed no variable outliers with distinctive Mahalanobis distance values.

Hypothesis testing.

Hypothesis testing was performed using SEM tools in the AMOS add-on to SPSS using methods suggested by Byrne (2010) and Hair, Black, Babin, and Anderson (2010). SEM was the preferred method for analysis and hypothesis testing because it “takes a confirmatory (i.e, hypothesis-testing) approach to the analysis of a structural theory bearing on some phenomenon” (Byrne, 2010, p. 3). A significant advantage of SEM is that it evaluated causal hypotheses in an explanatory model with all the theorized factors included. If the underlying equations of a SEM, represented by a graphical model of a system, were adequately fit with observed data, then the model suggests potentially useful causal relationships (Byrne, 2010).

As recommended by Hair et al. (2010), the measurement model validity was assessed before assessing the structural model validity. As described previously for instrument reliability and validity testing, measurement model validity was tested through CFA to confirm factor structure. Because the original theorized measurement model did not demonstrate good fit, Byrne (2010) and Hair et al. (2010) both recommended model respecification that was justified by empirical and theoretical support. For this study, the measurement model was respecified during CFA using criteria recommended by Byrne (2010) and Hair et al. (2010), to include an examination of the strength of standardized loadings and then using modification indicators in AMOS to suggest changes to improve model fit. Significant changes made to model structure are discussed in Chapter IV and V with the relevant theoretical support that accompanied the empirical evidence. After CFA of the respecified measurement model revealed a good model fit, then the full structural model of AGCAS-TAM was tested. To evaluate the measurement and structural models' respective fit in AMOS, relevant feasibility of parameter estimates, appropriateness of standard errors, statistical significance of parameter estimates, goodness-of-fit statistics, and the chi-square (χ^2) value were considered, as recommended by Byrne (2010). Relevant fit indices output by AMOS are listed in Chapter IV to include values for normed chi-square (χ^2/df), comparative fit index (CFI), root mean square error of approximation (RMSEA), normed fit index (NFI), goodness-of-fit index (GFI), and adjusted goodness-of-fit index (AGFI).

The χ^2 statistic is reported and is the "only statistically based SEM fit measure" (Hair, Black, Babin, & Anderson, 2010, p. 648). Low values of χ^2 demonstrate no differences between covariance matrices and "support the model as representative of the data" (Hair, Black, Babin, & Anderson, 2010, p. 648). However, the χ^2 statistic has limitations with respect to SEM because it is negatively affected by sample size and the number of observed variables considered. Therefore, Hair et al. (2010) and Byrne (2010) recommended using χ^2/df, which was also labeled CMIN/df, as a normed chi-square whereby the degrees of freedom serve to counter the effects of sample size and the number of variables. For this study, which used a relatively small sample size and a low degree of model complexity, Hair et al. (2010) recommend χ^2/df ratios of three to one or less. The NFI is a useful index for less complex models such as the one used in this study. The NFI is a derivation of a comparison between the hypothesized model and a null model (Byrne, 2010). The null model is one that "assumes all observed variables are uncorrelated" (Hair et al., 2010, p. 650). However, because the NFI may "underestimate fit in small samples" (Byrne, 2010, p. 78), the CFI takes the sample size into account. The range of values for NFI and CFI are between 0 and 1 where values closer to 1 indicate better model fit. CFI values were used in this study since the sample size is relatively small. RMSEA was assessed to test for the tendency of the χ^2 statistic to reject models with a large number of observed variables (Hair et al., 2010). RMSEA will better represent "how well the model fits the population, not just a sample used for estimation" (Hair et al., 2010, p. 649). Finally, GFI and AGFI were also included in this study as they are common SEM indices found in the literature. Values for GFI and AGFI may range between 0 and 1 where values closer to 1 indicate better model fit.

Hair et al. (2010) provided guidance for fit indices with various model situations. For the AGCAS-TAM, the number of observed variables and observations fell in the range where acceptable values included χ^2 p-values that may be significant with good fit, χ^2/df should be less than 3, CFI should be .95 or greater, and RMSEA should be less than .08. As suggested by Byrne (2010), other common index values in the literature NFI, GFI, and AGFI were included in the analysis. These criteria were used to determine goodness-of-fit for the measurement model and the structural hypothesis model analysis.

After determining model fit, parameter estimates in the model were assessed. If the parameter estimates were feasible and the standard errors output by AMOS were appropriate, the statistical significance of the parameter estimates could then be determined (Byrne, 2010). Parameter estimates should “exhibit the correct sign and size, and be consistent with underlying theory” (Byrne, 2010, p. 67). Small, but not too small, standard errors for each regression weight parameter estimate suggested accurate estimation (Byrne, 2010). The significance test statistic from AMOS for the parameter estimate was the C.R., “which represents the parameter estimate divided by its standard error” (Byrne, 2010, p. 68). For nonsignificant parameter estimates, the parameter was either unimportant to the model or indicated too small a sample size (Byrne, 2010).

“A theoretical model is considered valid to the extent that the parameter estimates are statistically significant and in the predicted direction” and “nontrivial” (Hair et al., 2010, p. 659). The AMOS SEM path estimates output indicated the relative strength of the deterministic influence or relationship among the constructs on each other.

Summary of the Methodology

This chapter described the proposed research approach and included the measurement model validity to precede the structural model analysis. The source of the data and the treatment of the data to protect the survey respondents' identities was provided. Pre-analysis treatment of the data was justified. Finally, the planned parameters, with acceptable ranges, to support measurement validity, structural model validity, and hypotheses testing were identified.

CHAPTER IV

RESULTS

This chapter states the results of the methodology described in the previous chapter. The results from the measurement model CFA analysis revealed validity problems and cross loading issues. The original hypothesis measurement model's CFA results suggested model respecification that is also supported by the literature. The modified model CFA and SEM analysis demonstrates adequate model fit and provided support for an Auto-GCAS specific version of a core TAM model with one of the original latent factors removed. The results from the subsequent structural model analysis revealed statistically significant support for two of the three remaining hypotheses.

Respondent Demographics and Ancillary Data

The Lyons et al. (2015) survey collected some quantifiable, confidential demographics of the respondents and some ancillary data. These demographic responses were made available for this study of acceptance as well. The responses included total flight hours, total F-16 flight hours, number of sorties (individual aircraft flights/missions) with AGCAS, and date of first AGCAS experience. These data were anonymous and represent the group of 142 respondents from a population of 495 USAF F-16 pilots that were flying AGCAS-equipped aircraft at the time of the survey in the summer of 2014. At the time of the survey, AGCAS had been fielded to the various flying units for one to three months, depending on location, since the system was not loaded onto all F-16 aircraft simultaneously.

The mean total flights hours for the pilots surveyed was 1,523 flight hours with a standard deviation of 925 flight hours. All respondents provided an answer to this survey question. The highest reported flight hours value was 4,600 flight hours. The frequency histogram for total flight hours is shown in Figure 9.

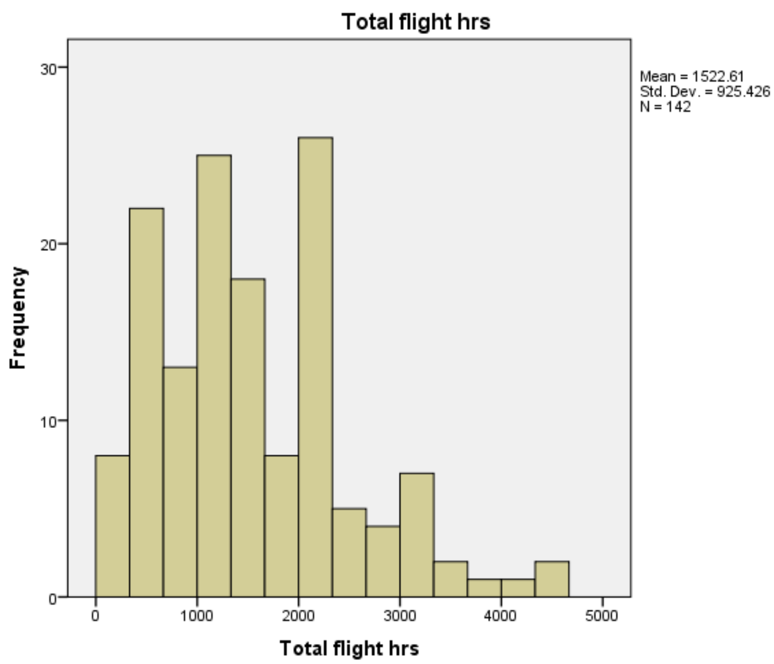

Figure 9. Survey demographics histogram for total flight hours.

The mean F-16 flight hours value was 923 flight hours with a standard deviation of 661 flight hours. All but three respondents provided answers to this survey question. The highest reported F-16 flight hours value was 2,800 flight hours. The frequency histogram for total flight hours is shown in Figure 10.

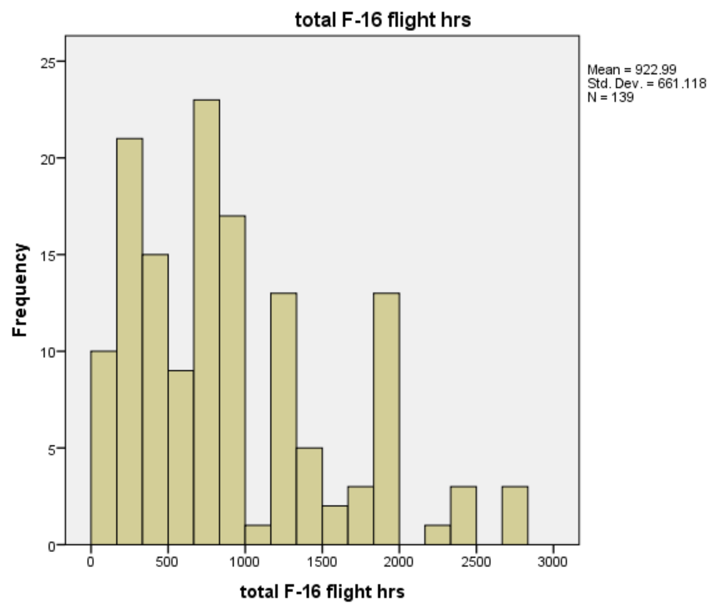

Figure 10. Survey demographics histogram for total F-16 flight hours.

The mean number of sorties with AGCAS was 45 sorties with a standard deviation of 25 sorties. All but three respondents provided answers to this survey question. The highest reported number of AGCAS sorties was 100.

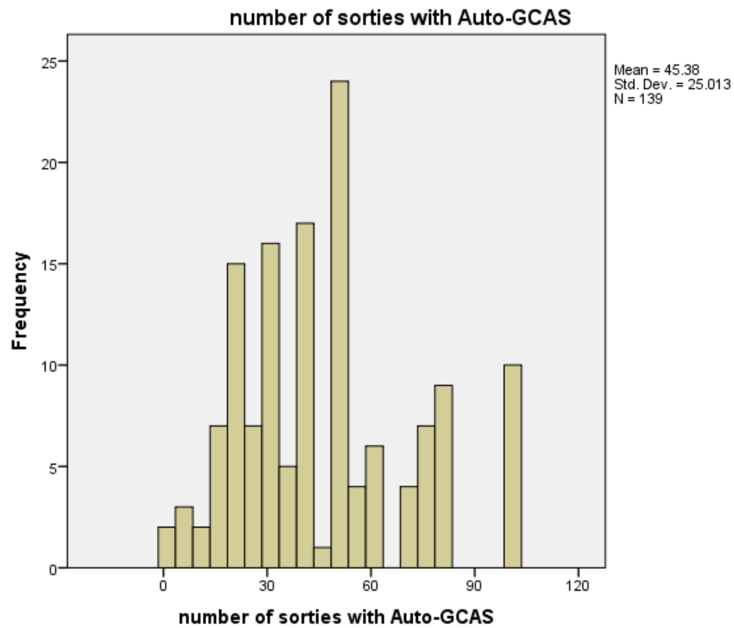

Figure 11. Survey demographics histogram for number of sorties with Auto-GCAS.

The demographics data is summarized in Table 3 below.

Table 3

Summary of Demographics Data

Survey question	Mean	Standard Deviation	Maximum
What are your approximate total flight hours?	1523 flight hours	925 flight hours	4600 flight hours
What are your approximate total F-16 flight hours?	923 flight hours	661 flight hours	2800 flight hours
Approximately how many sorties have you flown with AGCAS?	45 sorties	25 sorties	100 sorties

The Lyons et al. (2015) study survey also asked each respondent a binary (yes/no) question about whether or not the respondent had experienced an AGCAS activation. Only 17 respondents answered “Yes”, affirming that the respondent had experienced an AGCAS activation. Out of the 142 respondents 11 left this question unanswered or selected “N/A”, and 113 respondents selected “No”. The distribution of answers is shown in Figure 12.

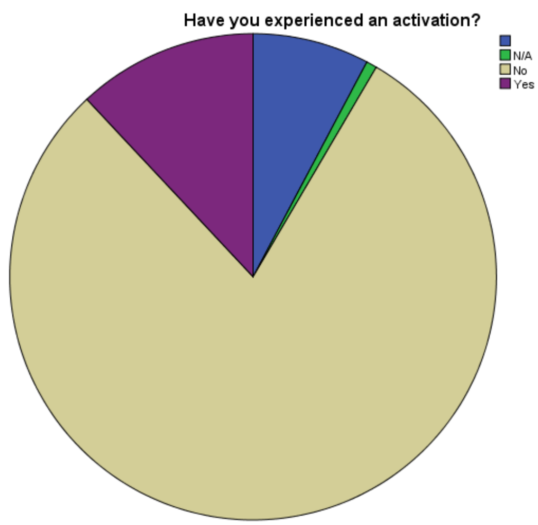

Figure 12. Respondent answers to survey question #11: “Have you experienced an activation?”

The survey did not specify or categorize the type of activation, so it is assumed that the pilots’ lack of AGCAS activations extends to any type of activation. Types of AGCAS activations include normal activations, erroneous activations, and nuisance activations (Moore, 2013). The majority of USAF F-16 pilots flying with AGCAS during the initial 1 to 3 month period of operation had not experienced a system activation. This result will be important during the discussion in the following chapter regarding the CFA model respecification to exclude the latent variable ABI in the AGCAS-TAM and the resulting adjustment to the hypotheses tested.

CFA and Model Respecification

This study was originally designed to test four hypotheses based on a proposed four factor Auto-GCAS specific TAM, as shown in Figure 8 and Table 2 in Chapter III. The results of a measurement model CFA analysis in AMOS of the original structure is shown below in Figure 13.

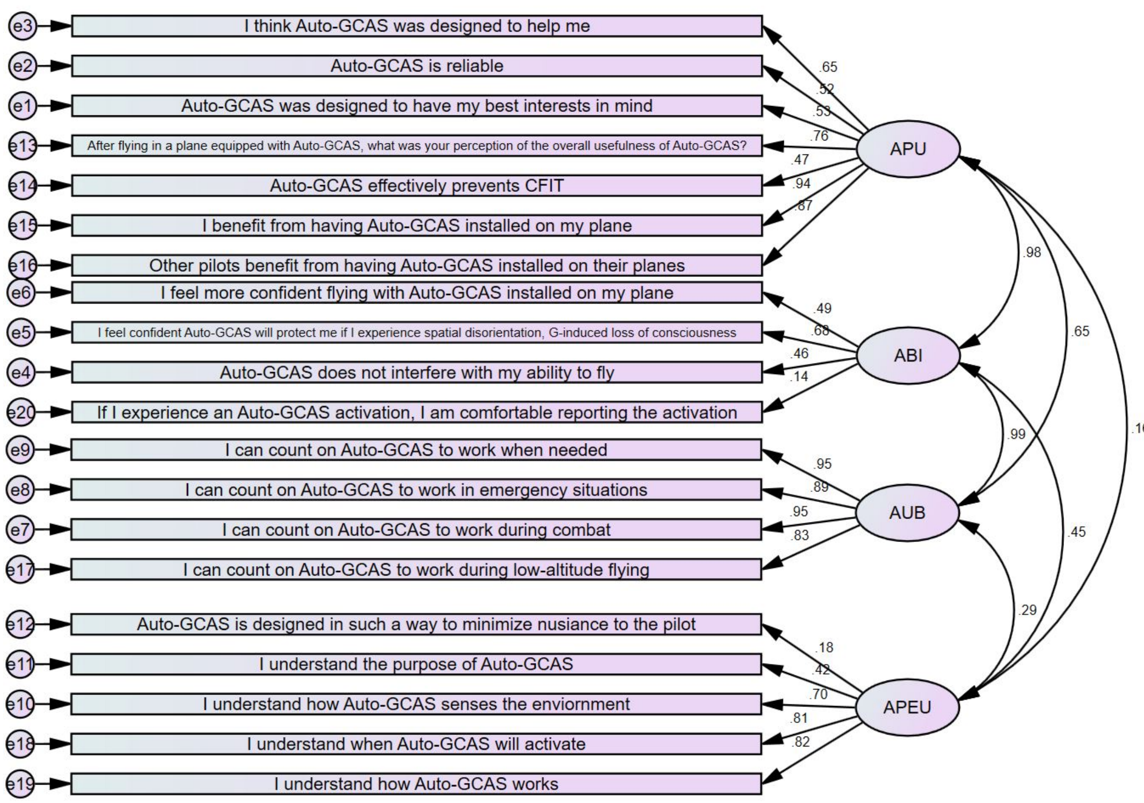

Figure 13. Measurement model CFA results of original proposed AGCAS-TAM with unacceptable fit and six standardized loading factors below minimum acceptable values.

The original measurement model arrangement failed Cronbach's alpha tests for reliability suggesting that the original proposed model structure, based on subject matter expert opinion only, was unlikely to fit the data. The model fit indicators from the CFA of the original hypothesized measurement model are shown in Table 4.

Table 4

CFA Fit Indicators for Original Hypothesized Measurement Model Before Respecificaiton

Indicator	Value	Result
CMIN (χ^2)	493.158, p<.0001	Too high for model size
CMIN/df (χ^2/df)	3.007	Not a unique model
CFI	.772	Poor fit for model size
RMSEA	.136	Poor fit
NFI	.698	Poor fit
GFI	.707	Poor fit
AGFI	.625	Poor fit

When the CFA with the original measurement model was analyzed in AMOS using the original measurement model from Table 2, it revealed poor model fit with values outside the recommended values in Hair et al. (2010) for a model with 20 measurement variables and 109 observations. Additionally, some standardized factor loadings were below the typical recommended minimum value of 0.5. Six of the twenty measurement variables failed to load with sufficient weight onto the latent variables. The potential reasons for these factor loading results are discussed further in Chapter V.

Using modification indicators (MIs) to rearrange observed variables with recommended latent factors, removal of those observed variables which failed to load onto any factor above the criteria detailed in Chapter III and following modification indicators suggestions to allow additional free parameters, a satisfactory respecified measurement model was found. As discussed in Chapter III, the methodology for analysis rearrangement followed guidance from Byrne (2010) and Hair et al. (2010). The respecified measurement model shown in Figure 14 and Table 5 satisfied recommendations for adequate model fit with a χ^2/df ratio (χ^2/df = 1.305) below the recommended maximum value and standardized loading weights above 0.5.

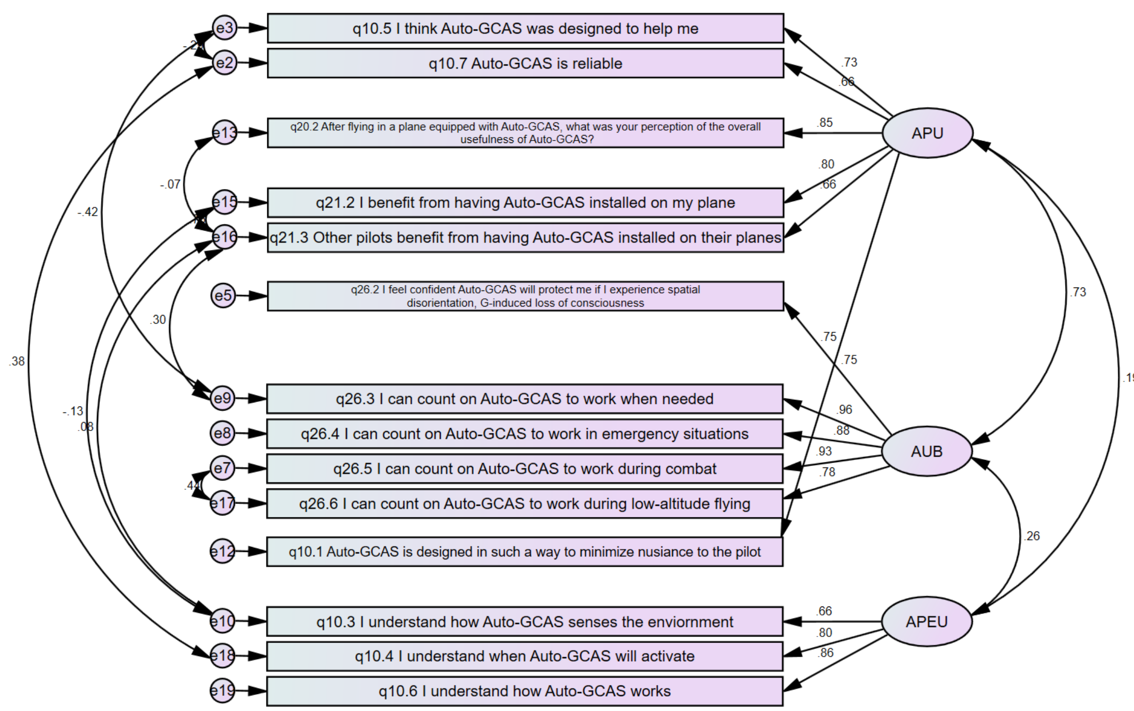

Figure 14. Respecified CFA measurement model with adequate fit and loading factors above minimum values.

Table 5

Question Numbers Sorted by Latent Variable in the Respecified AGCAS-TAM Model

Number/name	Actual question
Perceived Usefulness	
Q10.5	I think Auto-GCAS was designed to help me
Q10.7	Auto-GCAS is reliable
Q20.2	After flying in a plane equipped with Auto-GCAS, what was your perception of the overall usefulness of Auto-GCAS?
Q21.2	I benefit from having Auto-GCAS installed on my plane
Q21.3	Other pilots benefit from having Auto-GCAS installed on their planes
Q10.1*	Auto-GCAS is designed in such a way to minimize nuisance to the pilot
Perceived Ease of Use	
Q10.3	I understand how Auto-GCAS senses the environment
Q10.4	I understand when Auto-GCAS will activate
Q10.6	I understand how Auto-GCAS works
Usage Behavior	
Q26.2*	I feel confident Auto-GCAS will protect me if I experience spatial disorientation, G-induced loss of consciousness (G-LOC), or loss of consciousness
Q26.3	I can count on Auto-GCAS to work when needed
Q26.4	I can count on Auto-GCAS to work in emergency situations
Q26.5	I can count on Auto-GCAS to work during combat
Q26.6	I can count on Auto-GCAS to work during low-altitude flying

Note. * Indicates measurement variables reassigned to new latent variables during CFA respecification.

Table 5 shows the measurement variables that were retained during CFA analysis and model respecification. Additionally, the two questions marked with asterisks were reassigned to a different latent variable each. These two variable reassignments were suggested by AMOS during respecification and are visually apparent in a comparison of Figure 13 and Figure 14. The questions from the original hypothesized AGCAS-TAM structure that did not load well onto any latent variable regardless of respecification are shown in Table 6 below.

Table 6

Question Removed During Measurement Model CFA Respecification

Number/name	Actual question
Perceived Usefulness	
Q10.9	Auto-GCAS was designed to have my best interests in mind
Q21.1	Auto-GCAS effectively prevents CFIT
Perceived Ease of Use	
Q10.2	I understand the purpose of Auto-GCAS
Behavioral Intention*	
Q26.1	I feel more confident flying with Auto-GCAS installed on my plane
Q14	If I experience an Auto-GCAS activation, I am comfortable reporting the activation
Q10.8	Auto-GCAS does not interfere with my ability to fly

Note. * Behavioral Intention's fourth measurement variable, Q26.2, loaded more strongly onto Usage Behavior, thereby leaving the latent variable ABI with no measurement variable.

The removal of the six measurement variables shown in Table 6 from the original proposed AGCAS-TAM resulted in adequate model fit that passed the tests detailed in Chapter III for reliability and validity. The removal of questions Q26.1, Q14, Q10.8, and the reassignment of question 26.2 to AGCAS Usage Behavior based on minimum load factor weight requirements left the latent variable ABI with no measurement variable and therefore could not be retained for analysis in the final SEM model.

Table 7

CFA Fit Indicators for Respecified Measurement Model

Indicator	Value	Result
CMIN (χ^2)	84.822, p=.05	Expected for model size
CMIN/df (χ^2/df)	1.305	Unique model
CFI	.983	Good fit for model size
RMSEA	.053	Good fit for model size and CFI>.95
NFI	.932	Good fit
GFI	.901	Adequate fit
AGFI	.840	Adequate fit

When the CFA with the respecified measurement model was analyzed in AMOS using the new measurement model from Table 5, it revealed good model fit with values within the recommended values in Hair et al. (2010) for a model with 14 measurement variables and 109 observations.

After careful consideration and review of the literature, the construct of ABI was removed from the hypothesized structural model. Support for the model change is discussed further in the subsequent chapter. The resulting modified hypothesized structural model is shown in Figure 15 and Table 5. Because the analysis of the original proposed AGCAS-TAM did not achieve adequate fit with the data, it is not presented again in this chapter. The remainder of this chapter is organized around the modified hypothesized structural model in Figure 15.

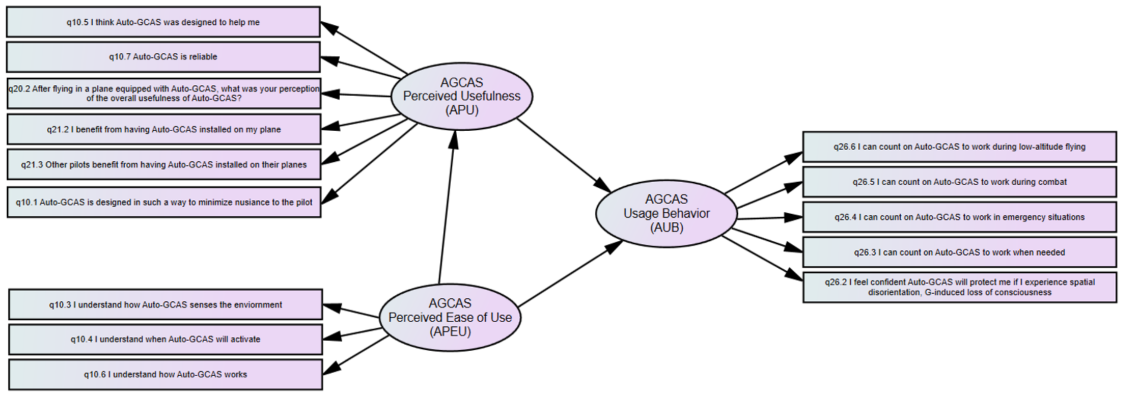

Figure 15. Structural model after CFA respecification.

After removal of the ABI factor, the Auto-GCASA TAM included only three paths and, therefore, only three hypotheses available for quantitative testing. The relative relationships remained the same except that APEU and APU weighted directly onto AUB. Therefore, the three remaining hypotheses are:

- H1: Pilots' perceived usefulness of AGCAS (APU) has an influence on pilots' AGCAS usage behavior (AUB).
- H2: Pilots' perceived ease of use of AGCAS (APEU) has an influence on pilots' perceived usefulness of AGCAS (APU).
- H3: Pilots' perceived ease of use of AGCAS (APEU) has an influence on pilots' AGCAS usage behavior (AUB).

Descriptive Statistics

Mean and standard deviations for each observed variable were calculated. These measurement variables are shown below, sorted by their respective latent variable from the modified measurement model in Figure 14**Error! Reference source not found.**. In general, the pilots tended to consistently answer affirmatively, e.g. "Agree", with positive statements regarding AGCAS. These quantitative results are consistent with qualitative results from the interview data collection methods in Lyons et al. (2015).

AGCAS perceived usefulness (APU) measurement variables. Descriptive statistics for the observed variables that loaded well onto APU following CFA respecification are summarized in Table 8. Higher values indicate agreement with the statement or question on a 7 point scale.

Table 8

Descriptive Statistics for the APU Measurement Variables

	Statements	Mean	Standard Deviation
Q10.5	I think Auto-GCAS was designed to help me	6.63	.79
Q10.7	Auto-GCAS is reliable	5.2	1.38
Q20.2	After flying in a plane equipped with Auto-GCAS, what was your perception of the overall usefulness of Auto-GCAS?	6.19	.908
Q21.2	I benefit from having Auto-GCAS installed on my plane	6.28	.992
Q21.3	Other pilots benefit from having Auto-GCAS installed on their planes	6.32	.891
Q10.1	Auto-GCAS is designed in such a way to minimize nuisance to the pilot	5.95	1.235

The pilots' answers were consistently in agreement with statements regarding the positive perception that AGCAS was useful. This tendency toward positive viewpoints regarding AGCAS usefulness was consistent with qualitative findings in Lyons et al. (2015), from which the quantitative data originated. In other words, the quantitative data appears to be consistent with pilots' qualitative comments that AGCAS was perceived as useful.

AGCAS perceived ease of use (APEU) measurement variables. Descriptive statistics for the observed variables that loaded well onto APEU following CFA respecification are summarized in Table 9. Higher values indicate agreement with the statement or question on a 7 point scale

Table 9

Descriptive Statistics for the APEU Measurement Variables

	Statements	Mean	Standard Deviation
Q10.3	I understand how Auto-GCAS senses the environment	6.2	.717
Q10.4	I understand when Auto-GCAS will activate	6.0	.805
Q10.6	I understand how Auto-GCAS works	6.06	.761

The pilots' answers were consistently in agreement with statements regarding the positive perception that AGCAS was easy to use. This tendency towards positive viewpoints regarding AGCAS ease of use was consistent with qualitative findings in Lyons et al. (2015), from which the quantitative data originated. In other words, the quantitative data appears to be consistent with pilots' qualitative comments that AGCAS was perceived as easy to use.

AGCAS usage behavior (AUB) measurement variables. Descriptive statistics for the observed variables that loaded well onto APU following CFA respecification are summarized in Table 10. Higher values indicate agreement with the statement or question on a 7 point scale

Table 10

Descriptive Statistics for the AUB Measurement Variables

	Statements	Mean	Standard Deviation
Q26.6	I can count on Auto-GCAS to work during low-altitude flying	5.52	1.143
Q26.5	I can count on Auto-GCAS to work during combat	5.52	1.288
Q26.4	I can count on Auto-GCAS to work in emergency situations	5.44	1.205
Q26.3	I can count on Auto-GCAS to work when needed	5.39	1.283
Q26.2	I feel confident Auto-GCAS will protect me if I experience spatial disorientation, G-induced loss of consciousness (G-LOC), or loss of consciousness	5.82	1.09

The pilots' answers were consistently in agreement with statements regarding the positive perception of AGCAS usage. This tendency toward positive viewpoints regarding AGCAS use was consistent with qualitative findings in Lyons et al. (2015), from which the quantitative data originated. In other words, the quantitative data appears to be consistent with pilots' qualitative comments that AGCAS was being used.

Missing Data

The archival data used for this study included 142 surveys completed by F-16 operational pilots from 10 U.S. Air Force installations around the world. At the time of data collection, the population of USAF F-16 pilots actively flying was 967, with 495 of those pilots flying an AGCAS capable version of the F-16. Of the 142 surveys, 109 were completed in their entirety, with all survey questions answered by the respondents.

All of the questions had some missing responses. Missing counts varied between 8 and 14 for all but one question on the survey. Question 14 of the survey showed 27 missing responses. Missing data was analyzed using the missing value analysis add-on in

SPSS. Missing patterns output showed a trend whereby a series of unanswered questions tended to be grouped. This appeared to be consistent with respondent behavior of submitting a survey without having answered all the questions before submission. The survey question order was randomized, and it appeared that most of the missing responses were primarily the result of users not answering several questions as they neared the end of their survey session. This result may indicate that the survey length may have been slightly excessive for about one fifth of the respondents or may simply indicate the volatility of the F16 pilots' time commitments.

One survey question, Q14, exhibited a noticeably higher missing value count compared with other questions. For Q14, 16 of the 27 counts for missing data were from responses where question 14 was the respondent's only unanswered question. Question 14 therefore stood out from the other questions in this regard and warranted unique analysis. Question 14 asked the pilots to agree or disagree with the statement "If I experience an Auto-GCAS activation, I am comfortable reporting the activation."

The qualitative results from the Lyons et al. (2015) study suggest that that pilots found Auto-GCAS to be reliable and mostly nuisance-free, and therefore some of the pilots may not have felt empowered to answer question 14 with confidence. This inference is also supported by the pilots' survey responses for question 11, shown in Figure 12**Error! Reference source not found.**, which indicate that the vast majority of pilots had not yet experienced an AGCAS activation at the time of survey. This lack of AGCAS activation experiences was reasonable since the system was designed only to work at the last possible moment, when all of the pilot's normal mitigations for CFIT have failed, and because the system was demonstrated in flight test to be extremely nuisance free (Moore, 2013). Stated otherwise, many of the F-16 pilots probably did not have an Auto-GCAS activation experience to draw from, at the time of survey, in order to formulate an adequate answer to question 14.

Missing value analysis was performed in SPSS for all the survey questions with emphasis on missing values for question 14. Results from SPSS revealed useful information to help choose an acceptable missing value technique. Comparisons of means and standard deviations of the original set of data, listwise deleted data, and pairwise deleted data showed no significant variations during technique comparisons. Listwise and pairwise deletions did not have an appreciable impact on the distribution of responses. Differences in means were all less than 3 percent different and standard deviations changed no more than 10 percent. Listwise deletion was the easiest available technique and avoided potential pitfalls of pairwise deletion or imputation methods. Listwise deletion also left a large enough sample size to be sufficient for SEM analysis. Therefore, all that remained was to determine, in order to satisfy the assumptions for meaningful SEM analysis using AMOS maximum likelihood estimation methods, was to ensure that the missing data was missing completely at random (MCAR).

In SPSS, Little's MCAR test revealed a chi-square (χ^2) value of 159.589 with 151 degrees of freedom (df) at a significant level (p) of p=.300, which indicates the randomness of the missing values for all the included survey questions (Truong, 2016). When question 14 was removed, Little's MCAR test was run and revealed a chi-square (χ^2) value of 173.794 with 171 df at a significant level (p) of p=.426, which also indicates the randomness of the missing values and a slight improvement. However, whether question 14 was removed or included, the MCAR test indicated that the sample only contained missing data that was missing completely at random. Therefore, all the original proposed observed variable questions from Table 2 were used at the start of measurement analysis with a listwise deletion technique applied.

Reliability Testing the Respecified Measurement Model

As previously stated, the original measurement model failed reliability tests. The results presented in this section are for the respecified model, which passed reliability tests. The Cronbach's alpha outcomes for the respecified measurement model are shown in Table 11. All the values are well above the recommended lower limit for acceptability of 0.7 (Hair et al., 2010; Nunnally 1978).

Table 11

Cronbach's Alpha Test Outcomes of Modified Measurement Model

Variables		Statements	Values
AGCAS Perceived Usefulness (APU)	Q10.5	I think Auto-GCAS was designed to help me	.862
	Q10.7	Auto-GCAS is reliable	
	Q20.2	After flying in a plane equipped with Auto-GCAS, what was your perception of the overall usefulness of Auto-GCAS?	
	Q21.2	I benefit from having Auto-GCAS installed on my plane	
	Q21.3	Other pilots benefit from having Auto-GCAS installed on their planes	
	Q10.1	Auto-GCAS is designed in such a way to minimize nuisance to the pilot	
AGCAS Perceived Ease of Use (APEU)	Q10.3	I understand how Auto-GCAS senses the environment	.824
	Q10.4	I understand when Auto-GCAS will activate	
	Q10.6	I understand how Auto-GCAS works	
AGCAS Usage Behavior (AUB)	Q26.6	I can count on Auto-GCAS to work during low-altitude flying	.933
	Q26.5	I can count on Auto-GCAS to work during combat	
	Q26.4	I can count on Auto-GCAS to work in emergency situations	
	Q26.3	I can count on Auto-GCAS to work when needed	
	Q26.2	I feel confident Auto-GCAS will protect me if I experience spatial disorientation, G-induced loss of consciousness (G-LOC), or loss of consciousness	

The standardized factor loadings (AMOS standardized regression weights) for the modified CFA measurement model are above the minimum recommended value of 0.5, as shown in Table 12.

Table 12

Standardized Factor Loadings of Modified CFA Measurement Model

Variables		Statements	Values
AGCAS Perceived Usefulness (APU)	Q10.5	I think Auto-GCAS was designed to help me	.73
	Q10.7	Auto-GCAS is reliable	.66
	Q20.2	After flying in a plane equipped with Auto-GCAS, what was your perception of the overall usefulness of Auto-GCAS?	.85
	Q21.2	I benefit from having Auto-GCAS installed on my plane	.80
	Q21.3	Other pilots benefit from having Auto-GCAS installed on their planes	.66
	Q10.1	Auto-GCAS is designed in such a way to minimize nuisance to the pilot	.75
AGCAS Perceived Ease of Use (APEU)	Q10.3	I understand how Auto-GCAS senses the environment	.66
	Q10.4	I understand when Auto-GCAS will activate	.80
	Q10.6	I understand how Auto-GCAS works	.86
AGCAS Usage Behavior (AUB)	Q26.6	I can count on Auto-GCAS to work during low-altitude flying	.78
	Q26.5	I can count on Auto-GCAS to work during combat	.93
	Q26.4	I can count on Auto-GCAS to work in emergency situations	.88
	Q26.3	I can count on Auto-GCAS to work when needed	.96
	Q26.2	I feel confident Auto-GCAS will protect me if I experience spatial disorientation, G-induced loss of consciousness (G-LOC), or loss of consciousness	.75

Instrument Validity

The original measurement model failed validity tests. The results presented in this section are for the respecified model, which passed validity tests. Construct validity testing included convergent and discriminant validity calculations using CFA model variance values output from AMOS. Average variance extracted and construct reliability values are shown in Table 13. These values exceed the minimum recommended values for both reliability values AVE (0.5) and CR (0.7).

Table 13

Average Variance Extracted (AVE) and Construct Reliability (CR) Values

Variables		Statements	AVE	CR
AGCAS Perceived Usefulness (APU)	Q10.5	I think Auto-GCAS was designed to help me	.555	.881
	Q10.7	Auto-GCAS is reliable		
	Q20.2	After flying in a plane equipped with Auto-GCAS, what was your perception of the overall usefulness of Auto-GCAS?		
	Q21.2	I benefit from having Auto-GCAS installed on my plane		
	Q21.3	Other pilots benefit from having Auto-GCAS installed on their planes		
	Q10.1	Auto-GCAS is designed in such a way to minimize nuisance to the pilot		
AGCAS Perceived Ease of Use (APEU)	Q10.3	I understand how Auto-GCAS senses the environment	.605	.820
	Q10.4	I understand when Auto-GCAS will activate		
	Q10.6	I understand how Auto-GCAS works		
AGCAS Usage Behavior (AUB)	Q26.6	I can count on Auto-GCAS to work during low-altitude flying	.746	.936
	Q26.5	I can count on Auto-GCAS to work during combat		
	Q26.4	I can count on Auto-GCAS to work in emergency situations		
	Q26.3	I can count on Auto-GCAS to work when needed		
	Q26.2	I feel confident Auto-GCAS will protect me if I experience spatial disorientation, G-induced loss of consciousness (G-LOC), or loss of consciousness		

Discriminant validity testing was evaluated by comparing AVE to the square of the correlation estimates. The correlation estimates and square of the correlation estimates are shown in Table 14. The AVE values exceed the square of the correlation estimates which indicates acceptable validity.

Table 14

Discriminant Validity Squared Correlations

Variables	Variable	Correlation	Square Correlation
AGCAS Perceived Usefulness (APU)	AGCAS Perceived Ease of Use (APEU)	.19	.036
AGCAS Perceived Ease of Use (APEU)	AGCAS Usage Behavior (AUB)	.73	.533
AGCAS Usage Behavior (AUB)	AGCAS Perceived Usefulness (APU)	.26	.068

Hypothesis Testing

After an acceptable measurement model was found, a structural model based on the respecified CFA measurement model was created by constraining a few required relationships. As previously explained, ABI was removed from the hypothesized structural model based on CFA results. This respecified structural model only contains three latent variables and, therefore, only three hypotheses that do not include ABI, as shown previously in Figure 14. In AMOS, this also required the addition of two error terms for the endogenous latent variables, APU and AUB. The structural model for hypothesis testing in the AMOS add-on to SPSS is shown in Figure 16.

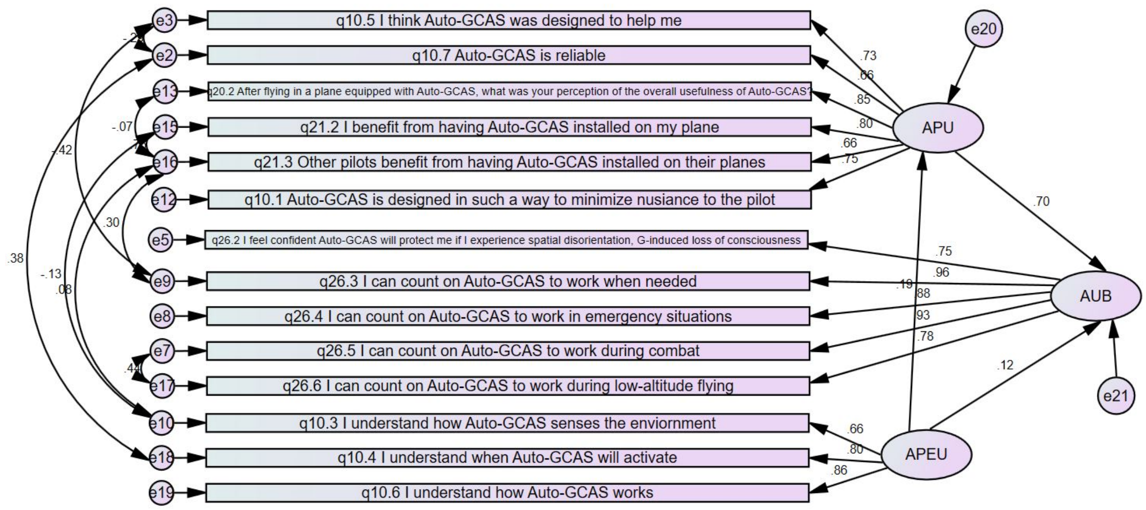

Figure 16. Structural hypothesis model in AMOS based on the respecified (only three latent variables) CFA measurement model with standardized loadings.

The structural hypothesis model had adequate model fit with a χ^2/df ratio (χ^2/df = 1.305). This value is below the recommended maximum value of 3 (Hair et al., 2010). The CFI value of .983 is close to 1 and indicates good model fit. The RMSEA of .053 indicates "reasonable errors of approximation in the population" (Byrne, 2010, p. 80). The NFI value of .930 is close to 1 and indicates good model fit. The GFI and AGFI values of .898 and .837, respectively, are close enough to 1 to indicate adequate model fit.

Table 15

SEM Fit Indicators for Respecified Measurement Model

Indicator	Value	Result
CMIN (χ^2)	84.822, p=.05	Expected for model size
CMIN/df (χ^2/df)	1.305	Unique model
CFI	.983	Good fit for model size
RMSEA	.053	Good fit for model size and CFI>.95
NFI	.930	Good fit
GFI	.898	Adequate fit
AGFI	.837	Adequate fit

Additionally, an examination of the path coefficients and loading estimates reveals that they have not changed substantially from the CFA model (Hair, Black, Babin, & Anderson, 2010). This indicates measured indicator variable parameter stability and that there is no problem due to interpretational confounding, which supports the measurement model's validity (Hair, Black, Babin, & Anderson, 2010).

The final step in analysis is to examine the individual parameter estimates between the latent variables of interest. This will provide the necessary quantitative support for the proposed hypothesized relationships. For ease of view, the AGCAS-TAM structural model has been summarized in Figure 17 to show the remaining relationships between the latent variables and their relevant measurement variables. Additionally, Figure 17 shows the AMOS results for the strength of the standardized parameter estimates and each estimate's statistical significance.

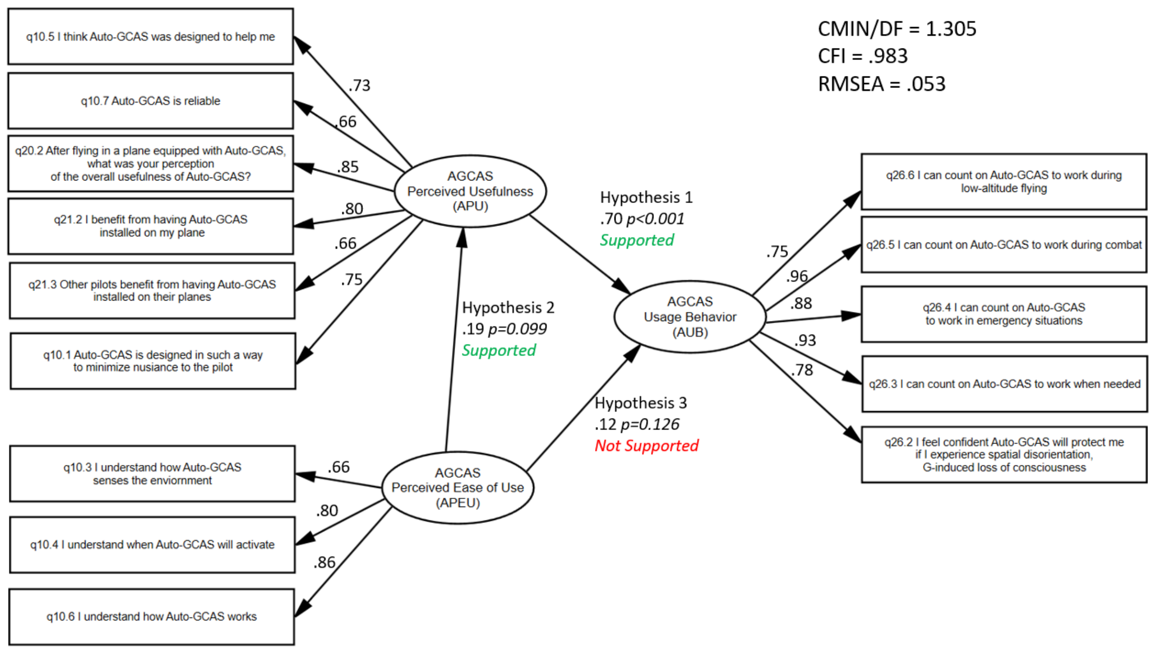

Figure 17. Respecified AGCAS-TAM structural equation model hypotheses outcomes with standardized loadings and latent variable loading significance values.

A summary of the hypotheses based on the respecified model results is also shown in Table 16. Hypothesis 1 is supported at the p<.05 level and hypothesis 2 is supported at the p<.1 level. However hypothesis 3 is not supported by the data in this model. These results indicate that the data support two of the three hypotheses within an AGCAS-TAM.

Table 16

Summary of Hypothesis Testing Results from the Respecified (ABI removed) AGCAS-TAM SEM

Hypothesis	Standardized Parameter Estimate	Significance Value	Result
H1*: Pilots' perceived usefulness of AGCAS (APU) has an influence on pilots' AGCAS usage behavior (AUB).	.70	p<.001	Supported
H2: Pilots' perceived ease of use of AGCAS (APEU) has an influence on pilots' perceived usefulness of AGCAS (APU).	.19	p=.099	Supported
H3*: Pilots' perceived ease of use of AGCAS (APEU) has an influence on pilots' AGCAS usage behavior (AUB).	.12	p=.126	Not Supported

Note. * ABI removed during CFA respecification. APU and APEU load directly to AUB.

Additionally, an analysis of the SEM that excluded the relationship for H3, and therefore removing the loading of APEU onto APU, did not significantly change the model fit or other parameter estimates. No other changes to the model were supported by theoretical justification, because model respecification should be done only with empirical and theoretical support (Hair, Black, Babin, & Anderson, 2010). Lacking support for respecification, the model shown in Figure 17 was the final version considered in this analysis.

Hypothesis 1 was supported and exhibited a loading factor of .70. This provides support that AGCAS perceived utility has a large positive effect on AGCAS usage behavior. Hypothesis 2 was supported and exhibited a loading factor of .19. This provides support that AGCAS perceived ease of use has a medium positive effect on

AGCAS perceived utility. An APEU and ABU relationship may still exist, but hypothesis 3 was not supported by the data in this study, and valid conclusions cannot be made regarding the relationship between AGCAS perceived ease of use and AGCAS usage behavior at this time.

Chapter Summary

This chapter has discussed the analysis of an AGCAS specific version of a model of technology acceptance. The original hypothesized structural model was built using a core version of TAM that was parsimonious and common in the literature on technology acceptance. From the structural model, a measurement model was created using archival survey data collected during a study of operational F-16 pilots' AGCAS trust development by pairing measurement variables (survey questions with quantitative response values) with constructs in the proposed AGCAS-TAM. This pairing was initially done with the assistance of subject matter expert opinion from researchers involved in the qualitative study of F-16 test pilots' AGCAS behavior. During analysis of the hypothesized measurement model, CFA results showed insufficient support for six measurement variables and part of the proposed AGCAS-TAM structure. With six of the twenty measurement variables removed, two measurement variables reassigned to different latent variables, and one latent variable removed altogether, a respecified version of an AGCAS-TAM, less the construct AGCAS Behavioral Intent, was found to fit the data well. Additional theoretical support for this respecification less one latent construct will be discussed in Chapter V.

The respecified measurement model was used to define a respective structural model with only three latent variables remaining in the model. With only three relationships remaining, only three hypotheses could be tested and not the original four hypotheses suggested in Chapter II. The respecified structural model was analyzed using common SEM methods, and analysis results indicated the model fit the data well. The loading factors between the three remaining relationships provided the basis for determining whether the data support the three respecified hypotheses. Two of the three loading factor values were found to be statistically significant, and their respective hypotheses were supported. The remaining hypothesis was not supported by the data in the AGCAS-TAM. Each of these hypotheses is discussed in the following final chapter.

CHAPTER V

DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS

This chapter discusses the results of the analysis as they impact the research question and the hypotheses, offers conclusions regarding the meaning of the respecified AGCAS-TAM, and makes recommendations for future research. The discussion of the research question and hypotheses will make comparisons between the original proposed model in Chapters I and II and the respecified model that resulted from analysis. Support for and the implications of the model respecification are addressed. Meaningful conclusions that were made based on analysis of the respecified AGCAS-TAM are explained. Practical implications of the analysis findings and conclusions are explored. Finally, recommendations are made for potential future research using AGCAS-TAM as a foundation for understanding fighter pilots acceptance behavior with respect to high level, low time available automatic collision avoidance systems.

Discussion

There was one research question in this study. The research question centered on the applicability of an AGCAS-TAM theoretical model. With respect to F-16 pilots' acceptance of AGCAS, what are the relationships among the factors: AGCAS perceived usefulness, AGCAS perceived ease of use, AGCAS behavioral intent, and AGCAS usage behavior? By examining an AGCAS acceptance model based on TAM, the utility of the underlying theory discussed in the literature review could be explored for AGCAS. Many versions of the TAM have been explored in the literature as it related to a wide variety of systems, but not until this study had the TAM been applied to a high level automatic collision avoidance system capable of arresting flight control from a pilot in flight. The literature on TAM demonstrated that TAM based models were robust and reliable across a wide spectrum of uses, and so it was expected that TAM would prove useful for explaining pilot AGCAS acceptance behavior as well.

The four core factors of a parsimonious TAM discussed in the literature review formed the foundation for the original proposed AGCAS specific TAM. This AGCAS-TAM related the four factors to each other consistent with previous uses of the model. Therefore, AGCAS-TAM was expected to take the same relative form as TAM used to explain many other users' technology acceptance behavior, in general. These four relationships factored onto one another in a directional and deterministic relationship within a complete structural model. The four relationships, based on theory and literature review, defined the four original hypotheses presented in previous chapters.

The first original hypothesis (H1) described the relationship between APU and ABI, whereby APU would have an influence on ABI. The second original hypothesis (H2) described the relationship between APEU and APU, whereby APEU would have an influence on APU. The third original hypothesis (H3) described the relationship between APEU and ABI, whereby APEU would have an influence on ABI. The final original hypothesis (H4) described the relationship between ABI and AUB, whereby ABI would have an influence on AUB. Of these hypotheses, H4 was eliminated from consideration, and H1 and H3 were respecified based on the measurement model CFA results. The respecified AGCAS-TAM did not include the latent variable ABI, and APU and APEU were related directly to AUB.

In addition to the empirical evidence presented in Chapter IV, two theoretical reasons were used to remove ABI from the model as well. The first reason for removal of ABI was measurement was likely made too late to determine behavioral intent. The second reason was that behavioral intent may not be a useful construct when applied to a safety system that is inherently not supposed to be used frequently.

The determination of late measurement was derived by considering the demographic data with respect to the definition of behavioral intent. As stated previously, behavioral intention "is a measure of the strength of one's intention to perform a specified behavior" (Davis, Bagozzi, & Warshaw, 1989, p. 984). However, the demographic data revealed that, on average, the pilots had already flown with AGCAS a significant number of times before responding to the survey. The mean number of sorties with AGCAS was 45 sorties with a standard deviation of 25 sorties. Only four pilots responded that they had flown less than five sorties with AGCAS active in their aircraft. This result was unexpected. The timing of the Lyons et al. (2015) study's data collection was meant to survey the pilots just as AGCAS was released to the operational F-16 pilots. The intended goal was to capture a sample of pilots with a distribution centered on zero flights with AGCAS, such that an approximately equal number of pilots would have and would have not flown with the system yet. The reason for the delayed survey collection is unknown, but it follows logically that efforts to measure behavioral intent would probably be polluted. The operational F-16 pilots had likely already formulated their attitude toward using the system and established their usage behavior. Stated otherwise, the pilots's usage behavior was already established at the time of the survey, and behavioral intent no longer served as a useful mediator between the factors in the model.

Another possibility for the lack of data supporting behavioral intent during measurement model analysis may be the applicability of the model itself to AGCAS.

AGCAS is inherently a safety system that was and is not supposed to be used frequently. AGCAS only activates when all other mitigations of CFIT have failed and the system is extremely nuisance free. The TAM, however, was originally formulated to explain users' acceptance behavior relative to information systems that would be in regular use. Most applications of TAM in the literature consistently extend the model's use to explaining user acceptance behavior of systems that were intended for regular use. Therefore, it is plausible that any attempt to measure users' behavioral intent for an automated safety system that the majority of the users would not interface with regularly is likely to fail. Stated otherwise, behavioral intent may not be a relevant construct for systems like AGCAS. However, it is not possible with this set of data, to determine with confidence if the measurement was taken too late to account for ABI or whether ABI is truly not relevant to AGCAS.

With ABI removed, the remaining constructs' relationships leave APU and APEU directly influencing AUB, and good model fit was achieved. The direction and magnitude of the relationships that remained appeared consistent with typical findings from studies relying on TAM in the literature. Typical results in the literature indicate that perceived utility tends to have a stronger influence than perceived ease of use on behavioral intent and, ultimately, users' usage behavior. Also consistent with trends from the literature, perceived ease of use did have a meaningful but relatively smaller influence on perceived utility. When considering only the statistically significant relationships in Figure 17 and Table 16, the data supports the respecified AGCAS-TAM relationships for H1 (APU influences AUB) and H2 (APEU influences APU).

The first hypothesis (H1) was supported, with significant results, by the data and was consistent with previous applications of TAM. Variations in APU were consistent with variations in ABU. Therefore, AGCAS perceived usefulness had a significant and strong positive influence on AGCAS usage behavior. Also, H1 revealed the strongest factor loading with the highest statistical power, suggesting it was the strongest empirical result of this study. The H1 empirical results suggest that AGCAS user's behavior is consistent with user behavior studied in previous research that used TAM based models. The practical implication of this hypothesis test for designers of aircraft systems similar to AGCAS is to suggest that a focus on perceived usefulness should have a strong influence on users' usage behavior. If future system designers of aircraft automatic collision avoidance systems are faced with limited resources, they would increase their chances of user acceptance of their systems by focusing on those features which promote the users' perception of system utility first.

The second hypothesis (H2) was supported, with significant results, by the data and was consistent with previous applications of TAM. Variations in APEU were consistent with variations in APU. Therefore, AGCAS perceived ease of use had a significant and medium positive influence on AGCAS perceived usefulness. The H2 factor loading was weaker than the H1 result with only a medium affect expected on APU. The H2 empirical results suggest that the relationship between users' perception of AGCAS ease of use and users' perception of AGCAS usefulness are consistent with user behavior studied in previous research that used TAM based models. The practical implication of this hypothesis test for designers of aircraft systems similar to AGCAS is to suggest that users' perception of AGCAS usefulness could be improved somewhat by promoting users' perception of the system's ease of use. After efforts to promote users' perception of system usefulness, future designers of aircraft automatic collision avoidance systems could further increase users' perception of usefulness by focusing on features which promote users' perception of ease of use.

The third hypothesis (H3) was not supported at an acceptable statistically significant level. With the data available, it was not possible to determine if the individual relationship between AGCAS perceived ease of use and AGCAS usage behavior was consistent with the literature. It is possible that a different or larger sample would have yielded higher power results. No new meaningful practical implication was made for this relationship in this study beyond the suggestion that a TAM based model appears to be useful in explaining users' behavior with respect to aircraft automated collision avoidance systems such as AGCAS, in general. The individual relationship testing in H3 may still be important, but that will need to be determined in future studies that attempt to analyze TAM based models of user behavior with respect to high-level aircraft automatic collision avoidance systems. If future studies demonstrate continued lack of support for the relationship between APEU and AUB, this relationship should be considered for removal from the theoretical models. This study represents the first such attempt to use a TAM based model for this type of emerging technology, and so in and of itself does not support changing the parsimonious underlying theory. Stated otherwise, users' perception of AGCAS ease of use may still be an important formative factor for AGCAS usage behavior, but this study was unable to find sufficient evidence to support the relationship.

Conclusion

This research intended to explore an application of the technology acceptance model to integration of the AGCAS in fighter aircraft operations. This study demonstrated the potential utility of a model for technology acceptance tailored to explain user acceptance behavior with respect to a high level fighter aircraft automated collision avoidance system. The AGCAS-TAM required respecification to achieve acceptable model fit during CFA and SEM analysis, but the data supported a model with the TAM structure foundation. The relationships between the constructs appeared consistent with expectations of user acceptance behavior from the literature. The supported hypotheses provide useful inferences that are consistent with Davis' (1986) practical goal to "provide valuable information for systems designers and implementers" (p. 12). Designers will be "better equipped to evaluate design ideas early in the system development process and make informed choices among alternative approaches" (Davis, 1986, p. 12). This study's conclusion that TAM is a useful model for explaining AGCAS usage behavior should serve as a foundation for future USAF pilot acceptance behavior research.

This study's findings are generalizable to the population of USAF fighter pilots for three reasons. First, the F-16 pilots sampled for this research came from 10 USAF installations across the world and were chosen, by design, for their representativeness of the population of F-16 pilots, in general. Second, due to the multi-role nature of the F-16, the diverse type of inflight maneuvers performed by F-16 pilots span the spectrum of maneuvers performed in other types of fighter aircraft. Finally, because there is no reason to suspect that USAF F-16 pilots differ, demographically-speaking, from other

USAF fighter pilots, it is reasonable to infer that the conclusions of this study are valid for the population of USAF fighter pilots, in general. However, inferences beyond the population of USAF fighter pilots, such as extensions to foreign fighter pilots or non-fighter pilots is not recommended. This limitation to generalizability should not be overly worrisome to current affected stakeholders. At present, the DoD has not published analysis that would suggest it is considering integration of high level automated collision avoidance systems beyond fighter aircraft platforms Defense Safety Oversight Council (2006).

Another limitation in this study was the size of the AGCAS-TAM structure. The sample of 142 respondents only supported a four factor structure. Now that AGCAS-TAM has been demonstrated as a useful foundation for fighter pilot acceptance behavior research, the next logical step will be to explore additional relevant factors. Many potential factors have been suggested in the literature, and future data collection efforts focused on more complex variations of AGCAS-TAM would be served to collect large sample sizes to maximize the likelihood of meaningful analysis results.

Two practically meaningful results in this study came from the AGCAS-TAM individual hypotheses that were statistically significant. The first practical result was to demonstrate that perceived ease of use had a significant, but only medium size effect on perceived usefulness. The other practical result was that perceived usefulness has a strong effect on usage behavior. These results suggest that stakeholders hoping to promote positive fighter pilot acceptance behavior would be wise to invest more heavily in methods that help the pilots effectively understand the usefulness of an automated collision avoidance system.

Future research efforts using AGCAS-TAM as a starting point for further exploration may follow several useful paths. The first path to consider is a more timely collection of data to examine the construct of behavioral intention. In this study, it was not possible to isolate the reason behavioral intent did not work in the model. A future study may be able to better center data collection at the initiation of the technology integration without any delay. If a sample could be collected with the distribution of users centered on zero experience with the system, it is suspected that behavioral intent may bare more meaning in a TAM variation. If said study again revealed behavioral intention did not fit in the model, it may be reasonably inferred that there is a more meaningful reason that behavioral intention does not fit in a TAM based on collision avoidance technology. As described previously, behavioral intention may not be an important factor when examining integration of safety systems where users' will not be expected to regularly interact with the system.

Another path that would likely bare meaningful results would be explorations of AGCAS-TAM variations that include more extrinsic factors such as those that have been used previously in TAM based model research. In particular, it is recommended that future research focus on determining factors that influence AGCAS perceived usefulness. Determining those factors would allow stakeholders interested in promoting integration of automated collision avoidance systems with more useful suggestions for improving their system designs and pilot integration techniques, such as training materials and publications.

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APPENDIX A

Permission to Use Research

-----Original Message-----
From: LYONS, JOSEPH B DR-03 USAF AFMC 711 HPW/RHXS
Sent: Thursday, April 23, 2015 10:35 AM
To: RICHARDSON, CASEY E Maj USAF AFMC 416 FLTS/F15SA DO
Cc: Ho, Nhut T (nhut.ho.51@csun.edu) (nhut.ho.51@csun.edu)
Subject: RE: Survey distribution links for bases

Hi Fletch,

No problem, let me know if I should just send the message to you or if you need me to send it directly to your advisor (or someone else) - happy to do either :)

There are three things I would like to mention:
1) data for your dissertation - you are free to slice and dice to your heart's content and you will have access to the full dataset. My only request is that pertinent findings be shared with the team so that we can provide the maximum benefit back to the AF. I know that you share this intent.
2) I have a personal interest in understanding the antecedents of trust in the context of Auto-GCAS, so that will be my personal focus in the data.
3) Publications (conference papers and journal articles) - the way I typically run projects is that any publications resulting from a team-oriented project will benefit the team. There will certainly be publication opportunities that result from this project (hopefully many) and you will be included in on those, and you can take the lead where you are interested - but I ask that you coordinate with the team to ensure we all on the same page.

Scoping the research is a good thing for a dissertation - there are endless possibilities so having clear set of questions you want to test is good. For SEM you'll need a large N so let's hope for a large response. We've also got Shaw AFB and other bases to coord with yet, so they could boost the N too. It will need to be cleaned of course, but looking at an EOY defense seems very reasonable. I know Nhut is on your committee (so you have good guidance) but I am always available for specific questions also.

1

I'm excited to have the survey started! - and I can't wait to see the results and response.

Cheers,
Joe

Figure A1. Written permission from Dr. Joseph Lyons to use Lyons et al. (2015) data.

APPENDIX B

IRB Approval

Embry-Riddle Aeronautical University
Application for IRB Approval
Exempt Determination

Principle Investigator: Casey Richardson **Other Investigators:** Dothang Truong **Role:** Student **Campus:** Daytona Beach **College:** COA

Project Title: Applications of the Technology Acceptance Model to Integration of the Automation Ground Collision Avoidance System in Fighter Aircraft Operations

Submission Date: 11/8/2016 **Determination Date:** 11/30/2016

Review Board Use Only

Initial Reviewer: Dr. Mike Wiggins/M.B. McLatchey

Exempt: Yes

Approved:

Mike Wiggins	MB McLatchey	November 23, 2016 Expires November 22, 2017
Pre-Reviewer Signature	Chair of the IRB Signature	Date of Approval / Expiration Date

Figure B1. Embry-Riddle Aeronautical University IRB approval of exempt research.